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SPACE BIOLOGY AND AEROSPACE MEDICINE

Vol. 17, No. 6, November-December 1983

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PRACTICAL APPLICATIONS OF ADVANCES IN AVIATION MEDICINE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 22 Feb 83) pp 4-10

[Article by P. V. Vasil'yev and A. A. Gyurdzhian]

[Text] Aviation medicine, as one of the medical disciplines in the Universal Decimal Classification (UDC), is listed under the heading of "Aviation and Space Medicine and Hygiene" (Index 613.693).

Being on the boundary between medical and engineering sciences, aviation medicine interacts closely with disciplines that service aviation and are listed under the heading of "Aeronautics. Aviation" (Index 629.73).

Let us recall the hierarchy of the main headings defining the place of aviation medicine and aviation in the UDC, which stress the scientific and applied nature of aviation medicine [1].

6. Applied Sciences

61 Medicine. 613 Hygiene. Personal Hygiene. 613.6 Occupational hazards. Industrial Hygiene. 613.69 Other Branches of Occupational Hygiene. 613.693 Aviation and Space Medicine and Hygiene. 62 Engineering. Technology. 629 Transportation Engineering. 629.7 Aviation and Cosmonautics. 629.73 Aeronautics. Aviation.

Inclusion of aviation medicine (according to the UDC) among hygienic disciplines should, we believe, be considered arbitrary to some extent, since physiological, clinical, psychological and other methods of investigation play an equal role in its development.

The applied nature of aviation medicine is attributable to the practical tasks of medical support of flights and protection of the health of passengers and personnel (flight crews and ground-based personnel). This is what determines its distinctions. Let us mention only two of them.

The first distinction is that the rapid development of aviation makes it necessary to solve operationally problems of medical support of safety and effectiveness of flights with the use of new equipment, new construction

materials and diverse flying conditions, with output of concrete conclusions and recommendations.

The second distinction ensues from the close collaboration between physicians and specialists in aviation engineering, which enriches the arsenal of methodological procedures, used by aviation physicians, as well as equipment, and (which is particularly important in our opinion) makes it possible to visualize and check in practice the validity of their theoretical constructions.

Thus, aviation medicine has a rather good opportunity to apply the most important methodological principle of using practice as a criterion of truth. This link between aviation medicine and aviation practice, and the immediacy of solving problems that ensues from this have led to a situation where aviation medicine turned out to play the role of leader among the medical disciplines in working out a number of issues of substantial interest to public health care.

We can single out the following basic directions in the development of aviation medicine: 1) investigation of the effects on the body of flight factors and their combinations; 2) search for means of protection against the deleterious effects of flight factors and conditions, as well as definition of relevant requirements and permissible norms; 3) elaboration of principles and methods of engineering psychological, ergonomic analysis of man-machine systems and tracking of the newly developed equipment; 4) validation of approaches and criteria for medical and psychological professional screening, system of dynamic medical monitoring and expert evaluation of flight and engineering personnel in aviation; 5) elaboration of methods for analysis of medical causes of flight accidents and conditions contributing to them in order to increase to the utmost the safety of accident-free flights.

Studies in each of the above-listed directions have also made a contribution to development of problems of substantial relevance to public health.

First direction. In-depth and systematic investigation of the effect on the body of diverse accelerations (overloads), in particular shock acceleration, related to abandoning a flight vehicle and making a parachute landing, as well as frequent and chronic accelerations, yielded some rather valuable information to clinical biomechanics of the skeletomuscular system, traumatology, orthopedics, sports and forensic medicine [2, 3].

It is common knowledge that aviation medicine plays a part in the study of intensive and prolonged exposure of the auditory system and entire body to noise, vibration and combinations thereof, in defining the permissible levels of noise and vibration factors in industry, development of personal and group protective measures and gear, as well as the appropriate system of medical monitoring and prevention.

Elaboration by aviation medical specialists of the thesis of "total protection" of the body against ultraloud noise, based on experimental proof of the high significance of overstimulation of mechanoreceptors of the skin and viscera in forming adverse responses of the body to noise [4], was an important contribution to development of the teaching on noise pathology.

The vast experience of aerospace medicine in studying the effect on man of exposure to an environment with different gas composition and altered barometric pressure, as well as experience in working with pressure chambers, were helpful to clinicians in elaborating methods of oxygen therapy and hyperbaric therapy. It was definitely useful too for the study of such a global problem as "man and his habitat."

Physiological and hygienic studies of adaptation to heat stress and hypoxia have the most direct bearing on medical support of large groups of people who work in a hot climate, in particular, in Central Asia and at moderate altitudes [5].

Aviation medicine has always devoted much attention to physiological mechanisms of spatial orientation and spatial illusions, various types of vertigo and motion sickness among flight personnel. There was systematic investigation of the role of the vestibular analyzer, other analyzers and systems of the body (vestibulosensory, vestibulomotor and vestibulovegetative reactions). All this advanced significantly the relevant branches of physiology and clinical medicine. For example, studies were made of vestibular functions in the presence of altered reactivity of the body, with exposure to radial accelerations, high temperatures, prolonged hypodynamia and sensory deprivations, various combinations of factors affecting the otolith and cupulo-endolymphatic parts of the vestibular system, as well as some biochemical aspects of increasing man's vestibular resistance [6].

The results of investigation of the hemodynamic distinctions in man exposed to vestibular stimuli were used with success in clinical treatment of patients with vascular and otoneurological diseases [7].

Investigation of problems related to survival of flight crews and passengers who have suffered a disaster and found themselves under extreme conditions for survival, in unusual climate and geographic regions, is one of the directions that is traditional for aviation medicine. No doubt, the experience of aviation medical specialists is quite important to such branches of medical science as medical geography, distinctions of status and reactions of the healthy and the sick in regions differing in climate and geographic conditions, as well as to the branch of science that our specialists call "survival medicine" [8, 9].

In recent years, problems of biorhythmology have gained particular popularity, in particular those referable to daily (so-called circadian) physiological rhythms. They are of practical importance to aviation medicine in connection with the regular transmeridional flights that cross several time zones, and the occurring desynchronosis between physiological rhythms and physical cycles of day and night. Investigation of these matters makes it possible to predict the work capacity of flight crews (as well as passengers) at different stages of flights, to solve the most difficult problems for aviation medical specialists pertaining to setting standards for flight work (with consideration of numerous factors and conditions), planning optimum work and rest schedules for flight crews and thus assuring flight safety. By virtue of the fact that the study of this problem is of vital importance to aviation, as well as because the routine practice of aircraft flights is the material for such investigations,

aviation medicine turned out, of course, to be one of the leaders in this field [10].

Second direction. We could have described rather extensively the contribution of aviation medicine to the study of hygiene of the work place, habitability of industrial premises, personal hygiene and personal protective gear, work and rest schedules. We shall limit ourselves to only a few examples.

Rapidly developing aviation engineering is making extremely broad use of the newest construction materials, in particular, synthetics. Aviation medicine is faced with the task of making operational studies of the toxicological properties and fire hazard of these synthetics (moreover, at different ambient temperatures, with different gas composition and chemical environments), as well as to give its opinion as to the possibility and conditions under which they can be used. For example, we should mention the contribution of aviation toxicology to the study of effects and regulations-related work with a number of new synthetic oils, hydraulic fluids, synthetic construction materials and plastics, as well as the combined effect of toxic agents and certain physical factors. We can add to this the experience in studies of toxic effects of toxic chemicals used, in particular, in agricultural aviation. The foregoing is also rather important to toxicology of other sectors of engineering [10, 11].

The principles, upon which are based the anti-G and pressure suits, can be applied and used to develop methods of controlling shock and collaptoid states, as well as in patient rehabilitation after long-term bed rest and cardiovascular diseases. Some of their modifications, with regional and local pulsed hyperbaric pressure factors synchronized with the heart rate, could play the part of an ancillary "method of external counterpulsation" for the cardiovascular system [12-15].

The World Labor Organization notes in its documents that the labor of aviation specialists is exceptionally diversified (flight personnel, air traffic controllers, ground-based engineering and technical personnel, personnel that work at airports, hangars, plants, etc.). This presents great difficulties with regard to hygienic support of labor in different sectors, regulation of standards and medical monitoring. It is known, for example, that the labor of technical personnel in hangars and those involved in loading and unloading work in the civil aviation is among the most traumatic according to incidence of accidents (on the level of the labor of lumberjacks and miners). This is also indicative of the responsible place of aviation medical specialists in the system of hygienic disciplines [16].

Finally, aviation medicine has developed the principles, organizational forms, indications and contraindications, as well as methods of transportation and inflight medical support for evacuation of the sick and wounded in aircraft. In recent years, this matter has become particularly urgent for public health care in view of the establishment of specialized medical centers and the need to urgently deliver patients to their destinations [11, 17, 18].

Third direction. The engineering-psychological and ergonomic analyses of man-machine or, more precisely, man-aircraft systems that are made by aviation medicine are of special interest.

In the last decades, aviation medicine has undergone noticeable evolution. The center of gravity of research is shifting more and more from the study of somatovegetative functions to nervous and mental functions in operator work pertaining to control of an aircraft [17, 19-21].

Aviation medicine has traveled a long road of investigation and use of data in anatomy, physiology, psychology and hygiene to form the specifications for aviation equipment under development, control systems for flight vehicles and systems for displaying information about flight parameters and status of equipment. The complexity of problems dealing with optimization of interaction between man and new equipment and automatic units, as well as achievement of maximum efficiency of man-aircraft systems, caused aviation medicine to take one of the leading places in practical work on problems of ergonomics and engineering psychology. The basic ergonomic standards [22 and others] were prepared with the participation of aviation medical specialists, they were involved in development of new automated and semi-automated systems for control and data display. A scrupulous study of the human factor enabled aviation physicians to obtain some rather representative material, which is used extensively by the designers of new equipment. As an example, we can cite the extensive data of applied anthropometry, formulated in the form of a special standard [23].

At the present time, the alliance of physicians and aviation engineers is the rule. It provides for their joint work at all stages of development of equipment, from the planning sketch to testing of finished specimens [24].

We should add to this the in-depth and comprehensive investigations pursued by aviation medicine concerning psychophysiological performance of operators in different special fields. All of the foregoing has a direct application in the most varied sectors of occupational medicine, it constitutes the foundation for investigation of basic problems of "man-labor," "interaction between the body and work tools during work" [19].

Fourth direction. Historically, aviation medicine began with the study of problems of screening applicants to be pilots. And, while the solution of problems of purely medical screening proceeded relatively smoothly, in working out problems of medicopsychological screening aviation medicine had to undergo some heated debates about the significance of individual psychological distinctions and capabilities of man. Be that as it may, at the present time the effectiveness of medical and psychological screening in aviation has been entirely proven. Screening and rejection of unsuitable candidates increase the reliability and safety of flights, and make it possible to realize great savings [25].

At the present time, the knowhow of aviation medicine is used extensively (more or less effectively) for professional screening in many other sectors of human endeavor. In particular, it is the basis for working out the system of cosmonaut screening. The priority of aviation medicine is indisputable in this regard [26].

Dynamic medical supervision of flight personnel, which includes regular medical and flight commissions, in-depth work-up, systematic intercommission follow-up, preflight, interflight and postflight check-ups, has probably no equal in its systematic performance and refinement [11, 17].

In solving problems of expert evaluation of fitness for flying, work capacity, setting individual standards for different types of flight work and rest schedules, rehabilitation after illness and stress related to accidents, aviation medicine had to deal with a number of fundamental general medical and physiological problems. These problems include determination of criteria and boundary between normal and pathology, functional disorders and premorbid states, determination of the range of fluctuation of normal physiological parameters for different individuals and groups of flight personnel at rest and at work, in the course of development of fatigue and overfatigue.

Work on defining the individual norm for specific conditions is particularly important and difficult. The fact of the matter is that the ranges of the norms established by the World Health Organization are rather wide. Refined and sophisticated methods are needed to define the individual norm, the "physiological and biochemical individuality" of man. In this respect too, aviation medicine has made considerable advances: existing methods are being constantly refined, new ones are being developed and their informativeness is being defined [27-29].

As an example, we could mention introduction into aviation medical practice of diagnostic, ultrasound Doppler cardiography, which permits probing of muscular structures and valves of the heart, determination of functional state and individual distinctions of coronary circulation and great vessels of the heart, evaluation of changes in cardiac output (stroke and minute volumes). The combined evaluation thus obtained of the functional state of a specific person (operator) under specific conditions makes it possible, in particular, to predict the individual's endurance of the sets of factors inherent in different types of flights [30-34].

The same applies to the method of arteriovenous pulsography, which permits determination of pressure in the jugular vein and calculation of circulatory parameters on the level of the right atrium and in the system of the pulmonary artery [35-39], as well as the method of occlusion plethysmography, which permits determination of pressure in the upper extremities and is bloodless [36].

The method developed for application of negative pressure to the lower half of the body (with use of vacuum gear) was further developed as a rather sensitive technique for graded functional loads on the cardiovascular system [41, 42]. Methods of volumetric oscillography have been refined, which permit examination of the vascular lumen, even in the presence of serious interference, as well as methods of plethysmography and many others.

In the process of development and refinement of methods based on modern advances in electronics, portable multichannel equipment is being created, which permits simultaneous recording of several physiological parameters in comparable form for integral evaluation of the functional state of the body, as well as its different systems and organs.

This equipment, together with specially developed sensors, cuffs, immobilization belts and devices permits automatic recording of the state of subjects who are far away, while engaged in work for a long period of time, without causing any significant discomfort [43-47].

Fifth direction. All of the endeavors of aviation medicine are aimed at increasing the safety of flights. They include investigation of medical and psychological causes, factors and conditions that provide for safety of flights and reliability of actions of flight, ground-based engineering and technical personnel and air traffic controllers. Aviation physicians participate in investigations of aircraft accidents; they study the causes and circumstances of flight incidents and contributory conditions; they monitor work and rest schedules, living conditions, studies and retraining of flight personnel when they transfer to new aviation equipment, simulator and flight training. On the basis of systemic analysis of the above-mentioned factors, recommendations are formulated for management and aviation personnel [11, 48, 49].

Although this system of medical support of flight safety requires constant improvement, it can serve as an example for other medical services concerned with assuring labor safety in many sectors of the national economy.

In the course of its inception and development, aviation medicine made broad use of theory and practical methodological knowhow of its older sisters--other medical disciplines referable to physiology, hygiene and clinical practice. At the present itme, aviation medicine can itself be helpful, using its advantageous position on the boundary between two disciplines, medicine and aviation.

In conclusion, we should like to express our profound conviction that it is only through constant strengthening of creative contact with representatives of other medical disciplines that there is an assurance of further progress of aviation medicine.

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SURVEYS

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SHIELDING PART OF BONE MARROW AS A METHOD OF LOCAL PROTECTION AGAINST COSMIC RADIATION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 20 Dec 82) pp 10-17

[Article by Ye. I. Vorob'yev, V. I. Yefimov and V. S. Shashkov]

[English abstract from source] This paper reviews existing data on bone marrow partial shielding in animal studies with reference to partial-body protection in space radiobiology and medicine. Analysis of the reported data indicates the efficacy of the method to protect animals (including dogs) exposed to gamma-radiation and high-energy protons. Experimental findings that demonstrate the effectiveness of bone marrow partial shielding show that this method may be used for partial-body protection in space flight.

[Text] The classical experiments of Jacobson et al. [1, 2], with shielding (lead shield) of the exposed spleen of irradiated mice, as well as the studies of a numbe of authors dealing with protection of other organs and parts of this animal's body, made it possible to advance the thesis that any tissue that is not damaged due to local shielding could become an endogenous protective factor in the body that is instrumental in attenuating the overall radiation damage. Subsequent comparison of biological effects under conditions of local protection of parts of the body containing tissues or organs that are subject to marked physiological regeneration (hemopoietic tissue, intestine) and parts that do not contain such tissues (liver, kidneys, muscles) revealed that there is a substantial protective effect when rapidly renewed tissues are shielded, in particular, bone marrow, spleen and small intestine. The effects of local protection of various organs and regions (parts) of the mammalian body have been illustrated in [3-6]. The results of examination of repair in frogs [7] and chicks [8] exposed to subtotal radiation indicate that the shielding effect is inherent not only in mammals.

The efficacy of local shielding is evident following exposure to both lethal and nonlethal doses of x- and gamma radiation, neutrons and protons [4, 9-20], with delivery of single, divided doses and chronic exposure to ionizing radiation [21-27], exposure using a constant or decreasing dose rate [28].

Researchers are trying to find the optimum version of local shielding of the body in experiments, where they alter the localization of shielding, area of shield protecting a part of the body, thickness of the shield determining the residual dosage under it, magnitude of exposure dose, animal species, as well as nature of irradiation (single or repeated exposure).

Since hemopoietic disturbances are largely involved in determining the outcome of radiation sickness, the interest in protective effect of shielding part of the hemopoietic tissue (bone marrow), which is exposed to highly penetrating radiation whatever the type of radiation because of its anatomical and topographic distinctions, is quite understandable. In the opinion of most researchers, in the case of delivery of up to 500-800 R radiation to animals, i.e., when there is prevalence of the hemopoietic syndrome in the clinical signs, the effect of local protection is usually related to protection of bone marrow [3, 13, 19, 26, 29-43].

When radiation dosage is increased to 1000 R or more, the protective effect of local shielding will depend to a significant extent on additional restriction of exposure of radiosensitive organs of the gastrointestinal tract in the shielded region, primarily the loops of small intestine [4, 8, 10, 14, 44-53]. In experimental studies of local protection by a shield, there may be organs referable to other than the hemopoietic system (bone marrow, spleen), such as the gastrointestinal tract, that are in the shielded zone. This often leads to ambiguous interpretation of the effect of local protection. For example, the best protective effect was noted with shielding of the abdomen in [4, 10, 14, 18, 50-52, 54], whereas in other studies [3, 19, 23, 24, 36-40] this was noted with shielding of the pelvic region and chest.

Evidently, we cannot rule out the possibility that these discrepancies are attributable to use of different radiation doses in the experiments. At the same time, the fact that the intestine and hemopoietic system influence one another is indisputable and, perhaps, is never as clearly manifest as during shielding. Isolated local protection of hemopoietic organs (bone marrow, spleen) is associated in all cases with functional and morphological activation in the gastrointestinal tract [55-62].

The question of quantitative and dose dependence of the effect of local protection, when radiation is delivered in the range of median lethal doses responsible for the hemopoietic syndrome of radiation sickness, on volume of shielded bone marrow, as well as overall exposure dose. In experiments on mice and rats, with shielding of part of the bone marrow when the residual dose under the shield reached 100-400 R, the segment of bone marrow protected in this way retained its subsequent capacity to restore hemopoiesis, as did bone marrow irradiated in the same dosage in vitro or in vivo when subsequently transplanted [26, 42, 63-69].

Investigation of changes in kinetics of different populations of hemopoietic tissue caused by radiation led to the conception that there is a special pool of hemopoietic stem cells [70, 71]. The advanced thesis, that the outcome of irradiation in the case of total, let alone subtotal exposure, depends on repopulation of remaining hemopoietic stem cells, was universally recognized [72-76 and others]. Thanks to the proposed method of so-called spleen colonies

[77, 78], it was possible to establish several quantitative characteristics of migration and acceptance of hemopoietic stem cells after irradiation, including cases of using protective measures and shielding of part of the bone marrow in particular [26, 27, 42, 71]. There has also been coverage in the literature of such an important question as effect of protection as a function of volume of shielded bone marrow. It was demonstrated that, to achieve the same degree of protection with comparable radiation doses, the absolute quantity of protected marrow must be increased in the series, mouse--rat--dog--monkey. Authors relate this to the difference in migration capacity of hemopoietic stem cells from the shielded region in different animal species [13, 25, 26].

With reference to the distinctions of the radiation syndrome in man, when exposed to nonuniform radiation, G. D. Baysogolov and A. K. Gus'kova validly note that it is necessary to conduct appropriate experiments on large laboratory animals to validate the use of local protection in man [79]. Studies conducted on dogs, as well as (isolated) monkeys and pigs exposed to sublethal and lethal doses of radiation confirmed the view that these animals had greater radioresistance when a limited part of the body and bone marrow were protected. In particular, V. S. Barkaya et al. [80], who shielded the lower leg of monkeys (total dose of gamma radiation 650-750 R, dosage beyond shield 40-45 R), observed survival of 2 out of 6 monkeys, versus 100% death of control animals. Haymaker et al. [81] used x-radiation on monkeys in a dosage of 600 R, with shielding of the head (6 R under the shield). While there were less marked cerebral changes in protected animals, blood leukocyte parameters did not differ in control and experimental animals over a 2-week period (the monkeys were sacrificed after 14 days). However, restoration of leukocyte count began earlier in the shielded monkeys. Red blood cell parameters (thrombocyte content, hemoglobin, hematocrit) were appreciably higher in them than controls. There was no anemia. Allen obtained similar data earlier in experiments with dogs [82]. When dogs were exposed to x-rays in an absolutely lethal dose (450 R), a lead shield was used for their head. Survival rate constituted 25%. There was attenuation or absence of such symptoms of acute radiation sickness as increased bleeding and infectious complications in dogs protected in this way. In interpreting these findings, it can be considered that, when the head is shielded, protection of the most important element of the hypothalamo-hypophyseal system and prevention of other cerebral changes are of great importance. Local protection of bone marrow in the occipital bones, mandible and superior cervical vertebrae may play a role in obtaining the integral protective effect in this case (higher survival rate). There are other authors [3, 19, 36-39, 52, 54] who also adhere to a similar view concerning the protective effect of shielding cranial bone marrow in animals exposed to the above-mentioned doses of radiation.

The following findings were made in dogs exposed to radiation in a dose of 450 R with a lead shield on one or two extremities: in the former case, there was 25% survival and in the latter, 75% [83]. The surviving dogs presented normalization of peripheral blood parameters and restoration of bone-marrow hemopoiesis. Cole et al. [35], who used a lead shield 8×16×0.3 cm in size over the cubital articulation (total dose of x-radiation 600 R), reported 100% survival of animals. A. V. Bogatyrev et al. [84], who repeated the experiments of the preceding authors, did not obtain survival of all animals

protected in the indicated way, but confirmed the fact that local shielding of part of the canine bone marrow during exposure to x-radiation in doses of 450 and 600 R is associated with an increase in survival rate. Analogous findings were made by G. S. Strelin et al. [85].

Unfortunately, virtually none of the cited authors indicated the residual dosage under the shield or the volume (quantity) of shielded bone marrow. Evidently, these authors used maximum shielding on large mammals, i.e., when the residual dosage to the protected bone marrow constituted 4-5% of the exposure dose and did not exceed 20-30 R. This is indicated, in particular, by the experiments of V. P. Baluda et al. [86]. They exposed dogs to sublethal doses of radiation with a lead bracelet around the right hind leg up to the knee joint (12-18 R local dose under the shield) and demonstrated that the hematological changes in animals exposed to whole body radiation in a dosage of 300 R were the same as in dogs exposed to 350 R with shielding. The dose reduction factor with local protection constituted 1.17 according to their data. O. V. Klestova et al. [87] reported on survival of dogs with acute radiation sickness (500 R radiation dosage) as a function of shielding different-sized segments of bone marrow. Thus, while all control animals exposed to whole-body radiation expired, the survival rates were 16.5, 31 and 80% among dogs with protected foot, one or two legs, respectively. In shielded animals, the course of radiation sickness was milder and distinct signs of start of restoration of hemopoiesis appeared 12 days after irradiation.

V. M. Zyablitskiy et al. [38] tested different versions of shielding red (active) or yellow (mainly inactive) bone marrow of dogs in volumes of 5 and 10%, respectively. Radiation doses constituted 300-500 R and under the shield they were 12-18 R. The authors concluded that local protection of 5% of active bone marrow of dogs was 1.7 times better according to survival rate than protection of 10% of the inactive marrow. Exposure of red bone marrow to 60-70 R did not lower its activity. For example, at the height of radiation sickness, the number of karyocytes remained in the normal range in the region exposed to such a dose. The data submitted in [89] are interesting: Dogs were given autologous or homologous bone marrow ($\sim 1.5 \cdot 10^9$ nuclear cells) after irradiation, or else part of their bone marrow was shielded during delivery of 500-700 R radiation. No differences were demonstrable in severity of the hemopoietic syndrome for the first 1-7 days between the two group of animals, as well as dogs given only therapeutic agents (antibiotics, vitamins, repeated blood transfusions). Combinations of shielding or bone marrow transplants with supportive therapy were about equally effective. These data indicate that, in dogs too, acceptance of transplanted cells occurred just like hemopoietic cells that migrate from a shielded bone marrow region in experiments with small laboratory animals [26, 42, 71 and others]. Incidentally, Cole et al. [35] assumed that the protective effect of shielding the knee joint with a lead cuff (3 cm long) could be attributable to preservation of $2\text{-}5 \cdot 10^9$ nuclear cells under the shield [42].

In assessing the minimal volume of bone marrow to be shielded so that an appreciable protective effect would be obtained after exposure to minimal absolutely lethal doses (MALD) of radiation, it was noted that 0.2-0.5% active bone marrow must be preserved in mice [72-90], 3.0% in rats [91] and 5-8% in dogs [19, 24, 36-40, 72, 88]. Shielding 5% of the bone marrow of pigs during

irradiation of the abdominal region in doses of 1250-1750 R (followed by symptomatic treatment) inhibited development of the hematological syndrome [92].

In the last 10-15 years, research on local protection began to acquire special meaning in view of space exploration. Researchers, who used knowhow accumulated in general radiobiology and radiation therapy pertaining to local protection, are trying to use the shielding effect to validate and develop local protection for cosmonauts. Efforts are being made to assess the protective effect of shielding relatively small volumes (parts) of the body in developing a method of local protection for the purposes and tasks of space radiobiology and medicine. In a large series of experiments on rats [4, 6, 10, 17, 49-51, 93, 94], a comprehensive study was made of the effect of shielding circumscribed parts of the body during exposure to gamma and proton radiation over a wide range of doses (from 600 to 1900 rad). Shields of different thickness and width were used. Having noted a maximum effect, with the above-mentioned radiation doses, with protection of the abdomen, the researchers also demonstrated distinct protection when the shielded region was exposed to 100 to 230-250 R. This enabled them to conclude that one can demonstrate a distinct protective effect from shielding if the following conditions are met: 1) the mass of protected tissues (primarily the intestine and hemopoietic organs) should constitute 10-12% of body mass; 2) the radiation dosage to the shielded region must be lowered (by choosing the appropriate shield) to one-fourth or less, as compared to the exposure dosage; 3) when there is less attenuation by the shield of the dose of local radiation or reduction of mass of shielded tissues, the protective effect diminishes appreciably.

In subsequent experiments on dogs exposed to acute gamma radiation in doses of 600 R with shielding of the head or the upper abdomen (in both cases, the mass of protected tissues constituted 11-13% of body mass), the results of tests on rats were confirmed. It was established that with doses under the shield of 150-300 R the survival rate was 57-86%, whereas absolute death was observed in control dogs. There was a higher survival rate in animals with shielding of part of the abdomen. This was manifested not only with a local dose under the shield of 150 R, but with less attenuation by the shield of the delivered dose (200-300 R). The lower the dosage under the shield, the milder the course of acute radiation sickness in the animals and the faster the recovery of blood. The high efficacy of shielding the abdominal region of dogs was attributed by the authors to protection of part of the intestine (mainly), part of the bone marrow (4-4.5 vertebrae, 2 ribs) and spleen [54].

In order to validate the applicability of local protection to cosmonauts, Yu. G. Grigor'yev, G. F. Nevskaya and other researchers [3, 19, 36-40] tried to determine the effect of local protection of hemopoietic tissue in special experiments on dogs exposed to high-energy protons (~250 MeV) in MALD (350 rad). Parts of the body equal in mass were shielded; they constituted 14-15% of total body mass and contained 5 to 14.5% of all bone marrow [95]. With a dose load to the protected regions of 20-30 rad, a clearcut dependence of severity of radiation sickness in the dogs and severity of the hematological syndrome on amount of bone marrow shielded during irradiation was demonstrated. With protection of 5-6% of the bone marrow, regardless of its localization, all of the animals survived a serious course of radiation sickness. A maximum protective effect was observed when the pelvic or chest region of the dogs was shielded

(containing 14.5 and 12.8% bone marrow, respectively). The clinical course of radiation sickness was the mildest in these animals. There was also a substantial effect from local protection after repeated (after 45 days) of the dogs to protons under analogous shielding conditions [23, 24]. The authors concluded that protection of about 15% of the active bone marrow in the body with delivery of MALD (25-30 rad dose under shield) could assure man's vital functions and work capacity with relatively mild course of radiation sickness [19, 36, 39]. When the local dose was increased to 70 rad to a similar part of the bone marrow (pelvic region), other irradiation conditions being equal, the signs of radiation sickness were somewhat more marked, whereas with a dose of >120 rad the possibility of complete survival of dogs exposed to acute high-energy proton radiation in a dosage responsible for development of the hemopoietic syndrome was doubtful [96]. Studies conducted by other researchers [97, 98] showed that the maximum dosage under the shield (with protection of 14.5% of total bone marrow also), with which there would be a substantial protective effect of shielding on dogs exposed to high-energy protons, may be 150 rad. The dogs were exposed to an absolutely lethal dose (400 rad) with shielding of the pelvic region. With a dose of 150 rad under the shield, all of the dogs survived acute radiation sickness; with a dosage of 250 rad, animal mortality was almost 90%, which was indicative of loss of compensatory capabilities of the shielded bone marrow region in this instance.

Thus, in spite of the fact that there are some differences between the results obtained by different researchers, the main conclusion that ensues from the above-cited studies raises no questions: the protective effect of shielding a limited part of the body during total-body irradiation of animals (including large mammals) is indicative of the efficacy of this measure. The protective efficacy of shielding, which is attributable to the ratio of volumes of protected and irradiated parts of the body, is determined by the dose load, both to the whole body and shielded part (dose under shield). It should be borne in mind that most of the experimental data that we know of pertaining to local protection were obtained as they relate to questions of general radiobiology and radiation therapy. At the same time, this method of protection has also been tested with exposure of animals to high-energy protons, which are one of the principal types of cosmic radiation.

It was established that, even with doses causing hemopoietic radiation damage, the important circumstance of the shielding effect is the level (mass, volume) of both shielded bone marrow and radiation load under the shield. Experimental determination has been made of the minimal volume of mammalian bone marrow, preservation of which is necessary for subsequent restoration of hemopoiesis and survival of animals. With increase in dose load to the shielded bone marrow, it is necessary to increase the volume (mass) of protected marrow and, conversely, with lower doses protection is obtained by shielding a smaller volume of hemopoietic tissue. Thus with maximum shielding of dogs, when the dose under the shield reaches 20-70 rad, protection of 5-7% active bone marrow prevents animal death due to acute radiation sickness. With increase in radiation load under the shield to 150 rad (the total dose being 350-400 rad), it is necessary to shield about 15% of the bone marrow (in relation to total amount in the body).

There is every reason to believe that the mechanism of postradiation recovery processes in the case of shielding part of the bone marrow has much in common

in different species of animals, and it is attributable primarily to preservation under the shield of cellular material and repopulation of irradiated hemopoietic tissue due to migration of hemopoietic stem cells from the protected region [13, 25, 26 and others]. Moreover, by protecting the hemopoietic system, the shielded bone marrow aids in accelerating postradiation repair in organs having no direct bearing on the hemopoietic system (primarily in the intestine, thyroid, testes, etc.) [27].

The aggregate of facts indicative of the effect of shielding part of the bone marrow of mammals (including dogs exposed to standard forms of radiation and high-energy protons) warrants consideration of this method as one of the methods of individual protection against radiation during spaceflights. This method of local protection may be effective against solar flare protons at different radiation doses, exposure to single and prolonged irradiation, low and high dose rates. There is no doubt that, with increase in total radiation dose (over 400 rad for man), it is necessary to shield the abdominal region, along with protection of bone marrow, which guarantees limitation of development of the intestinal syndrome of radiation sickness. Of course, local protection by means of shielding of part of the bone marrow cannot be set against the other effective method of local protection, shielding the abdominal regions [93].

A wise combination of both forms of shielding radiosensitive systems of the body (hemopoietic, gastrointestinal tract) makes it possible to approach from optimum positions the problem of local protection during manned flights aboard spacecraft. It should be noted that, apparently, the method of radioprotection proposed by the United States [99] is based expressly on this principle; it consists of use by cosmonauts of removable constrictive elements in the inside lining of the command module of a spacecraft for shielding of the most radiosensitive organs (digestive tract, spleen, bone marrow, extremities and head) during flight, which can be stowed in special pockets of the flight or space suit. The desirability of developing protective belts and shields is also recognized by Soviet authors [6]. The practical solution of this problem will increase the degree of protection of spacecraft crews during flights with onset of solar cosmic radiation (high-energy protons).

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UDC: 612.275.1-08:612.014.461.3

FLUID INTAKE AT HIGH ALTITUDES

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 19 Jul 82) pp 17-21

[Article by Ye. B. Gippenreyter, M. S. Belakovskiy and S. V. Chizhov]

[English abstract from source] The paper presents data on the water balance, factors responsible for water requirements and methods of maintaining optimum water balance in humans at high altitudes.

[Text] Human fluid balance at high altitudes has not been sufficiently investigated. This is attributable primarily to the complexity of this problem, since such factors as hypoxia, markedly low air humidity and temperature, as well as several others exert an additional influence on fluid loss, intake and redistribution in the mountains.

Fluid balance constitutes a mean of 2.2-2.8 ℓ/day in an adult person at normal temperature and air humidity. Fluid balance is maintained by adequate compensation of fluid loss (in urine, sweat, feces and exhaled air) by means of intake of fluid with beverages and food, as well as its formation as the end product of chemical conversions as a result of oxidation of nutrients. At the same time, the fluid balance could undergo substantial fluctuations under the influence of ambient temperature, air humidity, diet, level of physical activity, emotional state and other factors.

The body's fluid requirements are determined primarily by the ambient temperature. A physical load increases these requirements. Figure 1 is an isometric illustration of the effects of the above factors on fluid requirements [1].

According to Ullman [2], the fluid balance remains positive for the first few days at an altitude of 3450 m. Hannon et al. [3], Surks et al. [4] observed redistribution of fluid in the body (reduction of plasma volume and increase in volume of intracellular fluid) at high altitude with retention of fluid balance. Other authors found that there is absolute dehydration of the body at high altitudes, as well as substantial decrease in total water and plasma volume, with a negative fluid balance [5-9]. The high incidence of thrombosis and embolism during mountain expeditions is also indicative of chronic dehydration of the body during long stays at high altitudes.

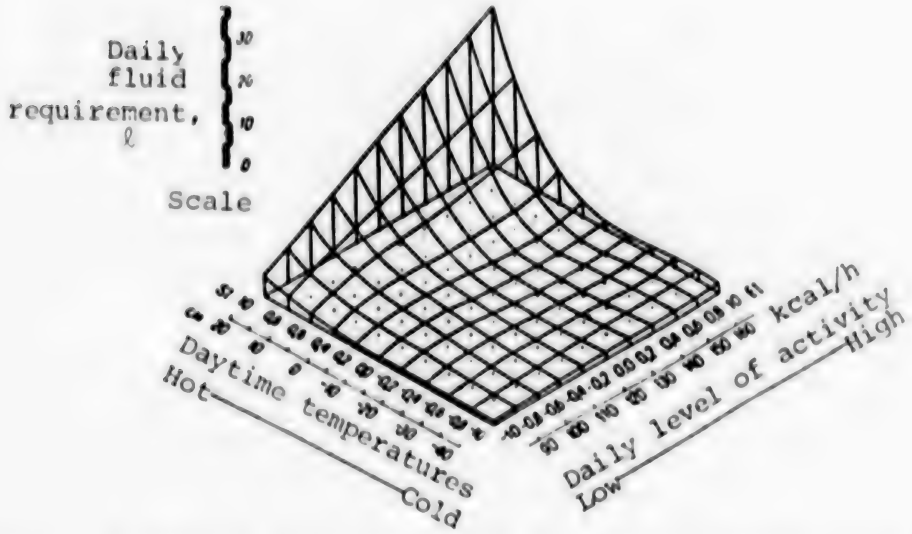


Figure 1. Isometric illustration of fluid requirements as a function of level of physical activity and ambient temperature [1]

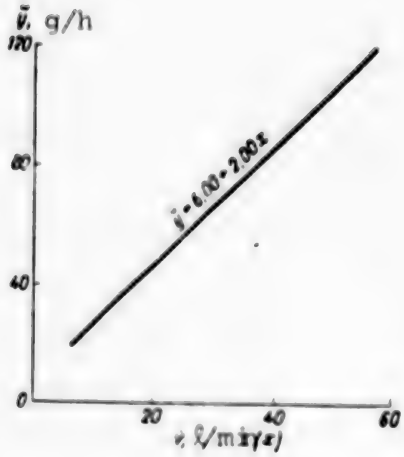


Figure 2.
Fluid loss through the respiratory tract (y) as a function of intensity of pulmonary ventilation (v) [10]

Calculated fluid loss through respiratory tract at different altitudes and different levels of metabolism [12]

Altitude, m	Fluid loss (ℓ/day) at following levels of metabolism (kcal/day)		
	2000	3000	4000
Sea level	0.35	0.52	0.69
6100	0.76	1.15	1.53
7315	0.94	1.41	1.88
8530	1.08	1.62	—

On the whole, it can be stated that the body's fluid requirement increases in the mountains due to greater output for different reasons. The body loses fluid in urine, feces, sweat, vomitus (in the case of acute altitude sickness), imperceptible cutaneous perspiration and through the lungs. The latter is the main route during mountain climing. Dry air entering the lungs is saturated there with water vapor and the moisture is lost during heavy breathing. The degree of fluid loss through the skin and respiratory tract depends on the pressure gradient of water vapor in the region between tissue and ambient air. Fluid loss during breathing depends chiefly on pulmonary ventilation (Figure 2) [10]. It has been established that if the pressure gradient of water vapor in the mouth-nose and ambient air section exceeds 20 mm about

13 mg fluid is lost per liter exhaled air [11]. The Table lists data on fluid loss through the respiratory tract at different altitudes [12].

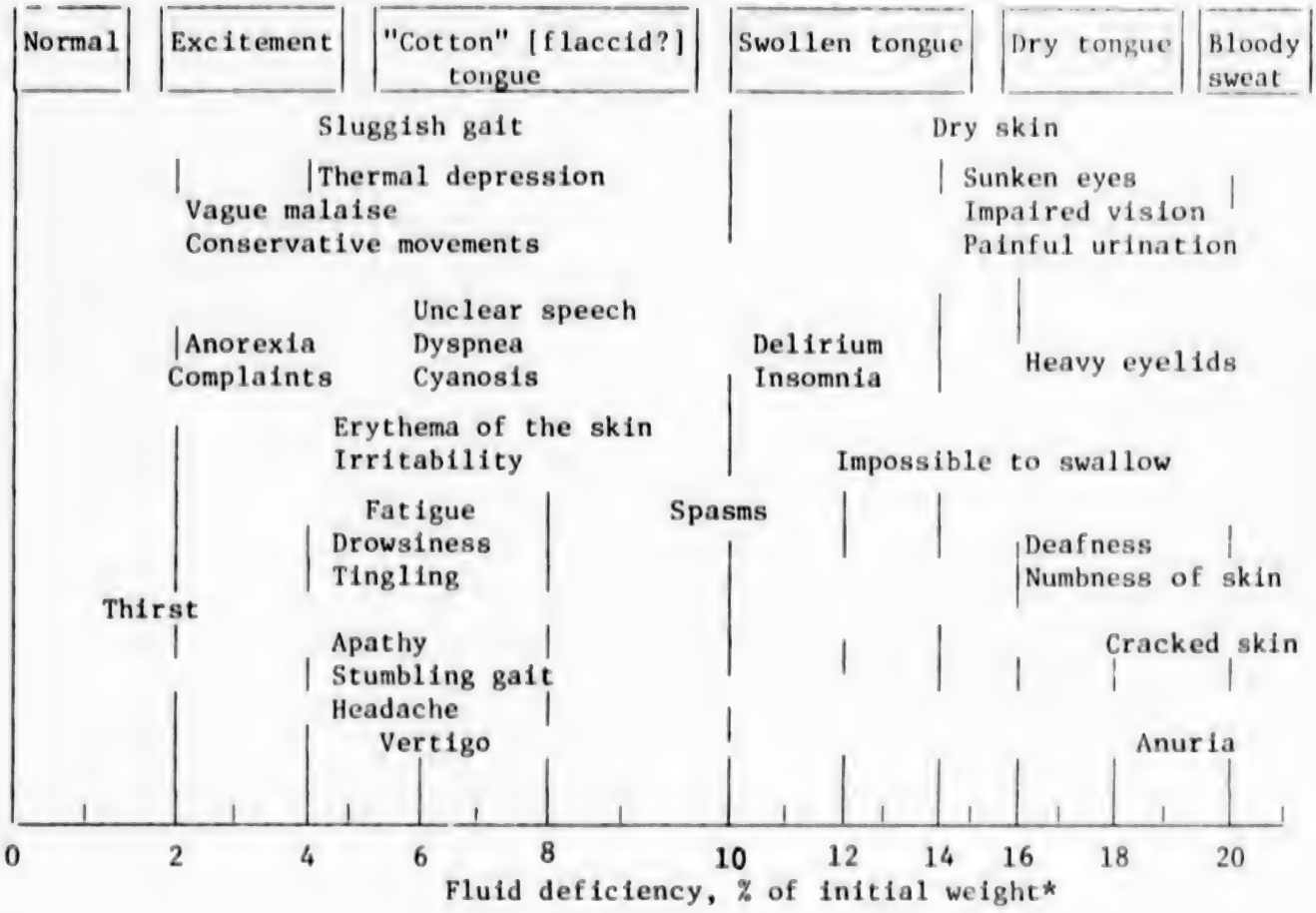
Fluid intake was 3-4 ℓ/day with diuresis of 1.2-1.5 ℓ/day at altitudes of 5334 and 6706 m in the Himalayas [12]. During a prolonged stay in the "Silver Hut" at an altitude of 5800 m, fluid balance increased by 30% but was not impaired due to adequate supply of liquid [13, 14].

As a result of direct measurements taken during the English expedition on Mt. Everest in 1953, it was found that 1.4 to 2 ℓ water was lost per day as a result of more intensive ventilation. This is about half the human daily requirements for water at high altitude and is 3-4 times greater than the loss when breathing in a temperate climate at sea level [15].

In the English expeditions to Cho-Oyyu in 1952 and Mt. Everest in 1953, fluid intake in the form of beverages constituted 2.8-3.9 ℓ/day and with food 0.28 ℓ, whereas during the ascent of Mt. Kanchenjunga in 1955 it constituted 3.36 ℓ/day. During the Mt. Everest expedition of the Swiss in 1952, this parameter constituted 0.6 ℓ/day. It is believed that one of the causes of failure of the last expedition was the marked dehydration of the climbers, which led to appreciable decline of physical work capacity and worsening of general condition of the members of the assault group [16]. According to Tentsing Norgey, the first to ascent Mt. Everest, the success of the British expedition in 1953 up this peak is attributable to the fact that its participants and mountain porters consumed large quantities of nimbu-pani (nimbu--lemon, pani--water), i.e., a beverage prepared from powdered lemon. One should not eat snow or drink cold snow water when one has a great thirst, because this would cause drying and inflammation of the throat. Under such conditions, it is recommended to drink soup, tea or coffee and, what is even better, lemon juice (lemon powder is mixed with sugar and warm water). Tentsing tells that "At the top of the mountain we consumed so much of this powder that I started to call this the 'lemonade' expedition'" [17]. Considering the importance of more intensive supply of water at high altitudes, the R. Messner-P. Habeler "link" drank 5-6 ℓ fluid (mainly in the form of tea) per day during their successful ascent of Mt. Everest in 1978 without oxygen, even when they were not thirsty [18].

It is very difficult and sometimes impossible to meet in practice the increasing fluid requirement during mountain climing. The only source of water at high altitudes is snow or ice, which must be melted. The recovered water must be used quickly, since it freezes. Because it is time-consuming to prepare drinking water under such conditions, intake is limited to the evenings, in the form of soup, tea, cocoa or other warm beverages.

As a rule, the mountaineers manage with their "pocket food" and flask of water in the morning and daytime. Insufficient fluid intake at high altitudes leads to impairment of fluid balance and development of gradual dehydration of the body, which ultimately has an adverse effect on well-being and work capacity of mountaineers. Dehydration is usually associated with the combined effect of other factors--hypoxia, cooling, inadequate diet, which enhance the effect of the former.



Ward reported progressive dehydration at altitudes in excess of 6700 m among members of the 1960-1961 Himalayan expedition, and this was particularly marked in those who did not use additional oxygen. The sensation of thirst was dulled and diuresis diminished. At over 7925 m, this parameter constituted about 500 mℓ/day [13].

Regardless of its causes (desert or mountain conditions), the fluid deficiency leads to appreciable systemic changes, even when it constitutes 1% of its total amount. With a 5-10% deficiency there is development of dehydration emaciation, while a fluid shortage corresponding to 20-25% weight loss leads to death [19].

Reeve et al. [20] postulated that 14 ℓ is the maximum tolerable fluid deficiency in the body. The diagram above [19] lists the typical signs of progressive build-up of functional changes associated with dehydration. This chart was taken from a book on human physiology in the desert, and it refers to dehydration in a hot climate, but it also applies, to some extent, to high altitudes.

The view is held that there is no adaptation to dehydration in man. Moderate dehydration is permissible and patience is necessary to endure it. Thirst

*Translator's note: Please note that spacing between scale graduations had to be altered to accommodate text.

usually determines the amount of fluid intake, although it lags somewhat from development of fluid deficiency in the body and does not always serve as its objective indicator. All of the proposed methods of relieving the sensation of thirst (keeping a pebble in the mouth, suck on candy drops, chew something, etc.) and alleviate the condition in such situations are not effective enough, they merely serve as a distraction. Only water can quench thirst. However, there are methods of lowering fluid loss during mountain expeditions: regulation of perspiration by altering physical activity, protection against overheating by means of clothing, reducing intake of food, which leads to appearance of substances in the body that require urine for elimination (protein, salts). In the latter case, this refers to temporary restriction of protein intake with increase in carbohydrates, since urea and other nitrous products of protein breakdown are formed in protein metabolism, and they require additional fluid for excretion in urine [19].

Diuresis with increase in overall concentration (specific gravity) of urine and elevation of internal body temperature are among the physiological changes that are aimed to conserve fluid loss when there is a fluid deficiency. However, both these reactions are relatively ineffective in this respect. Preliminary intake of extra amounts of water could augment the internal stock of fluid in the body, but only for a short time (about 1-2 h). For this reason, it is better to take a supply of water in flasks.

Diminished diuresis is observed during prolonged stays at high altitudes. At the same time, on the very first days of ascent one may observe intensification of diuresis, and this is apparently one of the mechanisms of adaptation to hypoxia: a decrease in overall fluid content of the body during this period lowers cerebrospinal fluid pressure and thus reduces the possibility of development of acute altitude sickness and particularly such of its complications as edema of the brain and lungs.

To sum up the data on fluid metabolism, we can state that there is a substantial increase in fluid outlay by the body in a high-altitude environment. This must be compensated by adequately increased fluid intake to avoid development of a fluid deficiency and dehydration of the body, which has an adverse effect on well-being, morale and work capacity of mountaineers.

The fluid balance should be maintained by means of both increased fluid intake and use of known methods of more conservative expenditure of fluid. A mountain climber must make the necessary effort and spend the necessary time to see that he has an adequate supply of water, to the extent this is possible, even if this means spending time scheduled for sleep, rest and work on the climb. During mountain expeditions, it is recommended to take 3 ℓ water per person in the form of beverages and food, and at least 4 ℓ/day when physically active at high altitudes.

Since fluid is lost during mountain ascents mainly through the lungs, there is no need for special (supplemental) intake of salt tablets, since chloride loss is not so great and requirements for chlorides are met with the table salt consumed in food. However, since only water melted from snow and ice is used for drinking purposes at high altitudes, and it contains virtually no minerals, it is desirable to mineralize it artificially.

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EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

UDC: 629.78:[612.821+612.766.1

MENTAL STATUS AND WORK CAPACITY OF SALYUT-6 STATION CREW MEMBERS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 28 Oct 82) pp 22-25

[Article* by V. I. Myasnikov]

[English abstract from source] The psychic status and work capacity of prime crewmembers of missions 1 and 5 onboard Salyut-6 were investigated, using objective (scope, time and quality of the work performed) and subjective (fatigue, mood variation, complaints) parameters. Based on these parameters, it was possible to identify several stages in the dynamics of the psychic status and work capacity: stage of acute adaptation, stage of complete compensation (2-3 or 4 months), stage of incomplete compensation (3 or 4-5 months), and stage of final "breakaway" (last month). These stages reflect the process of psychic and professional adaptation to space flight. The process of adaptation is strongly affected by the rational work-rest cycle, in which the sleep period coincides with that associated with Moscow time, and events of psychological support. The results show that crewmembers may well adapt and work in space flight for a long time.

[Text] Analysis of professional performance of cosmonauts referable to various work operations and assessment of man's psychophysiological capacities for control of the craft and its systems during short-term orbital flights aboard the Soyuz series of spacecraft revealed [1] that, in spite of "quite complete fulfillment of the programs," the problem of professional performance of cosmonauts requires further optimization, primarily by means of a wise work and rest schedule for crews. This conclusion of the authors is attributable, in our opinion, to the fact that previously the daily schedule during missions aboard the Soyuz series spacecraft was based on the principle of so-called migrating days, i.e., with a 25-30 min (clockwise or counterclockwise) daily shift of the sleep-waking cycle in relation to its usual place on Moscow time [2]. On some days of the mission, the time to start sleep was shifted to by 7.5 h in relation to the Moscow time of 2300 hours [3]. In the opinion of the cosmonauts this was the principal cause of onset of

*In writing this paper we used data obtained by O. P. Kozerenko, F. N. Uskov, V. I. Makarov and A. Ya. Tizul during medical support of missions aboard Salyut-6 orbital station.

fatigue and diminished work capacity. With such a schedule, the cosmonauts' main scourge was sleep. And it was even not sleep, but the daily schedule. It shifts by 0.50 h every day [4].

Thus, the work and rest schedule that was used, combined with the adverse flight factors (weightlessness, noise, distance from earth, monotonous conditions, etc.) determined the mental state of the cosmonaut, his work capacity and dynamics of these parameters during spaceflights.

During the missions of the EO-1--EO-5 crews, the mental state and work capacity of the cosmonauts as base criteria for evaluating their adaptation to flight conditions and factors cannot be examined solely in the light of the deleterious factors of long-term spaceflights. It is necessary to take into consideration the optimizing factors, which were first used on the Salyut-6 orbital station: daily schedule based on a 24-h sleep-waking cycle, with the sleep periods coinciding with night hours on Moscow time, purposeful use of psychopreventive and psychocorrective measures--so-called psychological support.

Mental state and work capacity are concepts that differ in their meaning. While the mental status is an integral characteristic of mental activity over a specific period of time [5], work capacity of an operator, which is determined by the status of physiological and psychological functions, characterizes his ability to perform a specific activity of the required quality and for the required time [6].

The specifics of a cosmonaut's professional activities (high degree of responsibility, diversity and number of tasks), which are a combination of elements of operator and research engineer work, create some difficulties with regard to choice of methods and criteria for evaluation. We used the method of combined evaluation based on parameters of productivity of work and functional state, which has earned a good name for itself in medicine and psychology, as our methodological approach.

It was possible to arbitrarily distinguish between mental state and work capacity over a series of periods on the basis of objective (volume, time and quality of performance of work, number and nature of operator errors, individual style of work and behavior in regular and irregular situations, capacity for correction when there are mistakes and malfunctions, etc.) and subjective (feeling of fatigue, somatovegetative complaints, mood fluctuations, changes in voice timbre and other quantitative and qualitative characteristics of speech, etc.) parameters.

However, before we describe these periods, we should discuss two important circumstances that play a substantial role in manifestation of adaptive reactions and efficiency of performance.

In the first place, experience in medical support of manned flights has shown that there is a close correlation between mental status, work capacity and external scheduled factors: responsible operations such as "docking," "extravehicular activity," "reception of visiting missions and cargo transport ships." As a rule, the external scheduled factors had a strong mobilizing effect on the condition of the crew and they were associated with efficient work.

In the second place, there is the relationship, which the cosmonauts realize, between their condition, well-being and the work load. As a rule, heavy (within certain limits) work loads were associated with good well-being heightened affect and creative activity. Conversly, during periods characterized by a relatively light program combined with monotonously repetitive operations and tests, direct or indirect signs of negative change in mental status were observed more often. Perhaps this explains the increased interest of cosmonauts in work that requires initiative.

The acute period of adaptation to weightlessness was notable primarily by a smooth course, with some individual distinctions. For some cosmonauts, this period was characterized by vestibular discomfort with clinical signs in the form of nausea at rest, retching, particularly during abrupt head movements, illusions of body position, marked sensation of blood rushing to the head and temporary decline of work capacity. Several operator errors were also noted. These functional disturbances lasted an average of 7 days (with a peak on the 3d-4th day).

The period of feeling at home in the station and getting into the swing of their work loads lasted 1 month. The period of complete compensation (2d-4th months) was characterized by further stabilization of mental state and work capacity. At the same time, in several instances the EO-1--EO-5 crews showed some deviations in the emotional and motivational sphere, which could be related to the heavy work schedule in the 1st month: during the 96-day mission there was reactivation of the station and the "EVA" operation on the 10th day of the mission; during the 75-day flight, the same reactivation, overhaul, work with Progress-12, reception of visiting expedition on the 10th day of the flight. In this connection, there were complaints of fatigue at the end of the work day, sensation of blood rushing to the head and changes in sleep.

In the opinion of D. Lindsley [7], insufficient sleep affects performance of professional tasks, most often those related to interpretation of information about controlling the spacecraft, detection of unexpected and insignificant deviations in the nature of incoming information, etc. Responsible operator work was not scheduled for 2 days after a "sleep shift" of more than 2 h, in order to rule out any possible adverse consequences, starting with EO-3.

As a result, the EO-3 crew performed difficult scheduled work with the Soyuz-34 transport craft and Progress-10 cargo craft on a high professional level, while the EO-4 crew received and implemented the visit of the international Soviet-Vietnamese crew.

During the "last dash" period (last month of the mission), the cosmonauts exhibited high motivation for work and very coordinated actions. The actions of EO-3 in open space on the 171st day of the flight was a vivid example of this.

It must be noted that the periods we have distinguished in the adaptation process are arbitrary. Such periods were observed in all cosmonauts, although their duration and degree of manifestation varied. For example, the period of complete compensation was longer during the 140--175- and 185-day missions,

which could be attributed to the social set of the crews. Set played the part of a mobilizing and supporting factor of mental activity in flight.

If we were to assess the work capacity of the crews on the five missions, according to medical monitoring data it remained at an adequate level for the cosmonauts to fulfill the lengthy and heavy work schedule. According to I. I. Bazhinov [8], there was a total of 27 dockings of spacecraft with the station in the course of the 4 main missions, 4 redockings from one part of the station to another, 15 landings of Soyuz and Soyuz T craft, as well as 12 descents of the Progress craft. The spacecraft and station performed over 160 maneuvers in orbit during this time.

Furthermore, the EO-2 crew performed 55 experiments dealing with materials technology using the "Crystal" and "Alloy 01" installations, as well as about 50 biomedical experiments. The EO-3 crew performed a large volume of preventive and maintenance-overhaul work aboard Salyut-6.

In addition, there were repeated instances of performing not only the scheduled work, but various observations and experiments at the crew's initiative.

The measures for psychological support played an appreciable part in maintaining a high emotional and work tonus in EO-1--EO-5 crew members: "... the conversations with the ground gave us much pleasure. The communication sessions, whch were superimposed over the general tension of work, create a special 'channel' for the mood" [9].

During the period of the 5 main expeditions, an onboard video and record library was organized for the cosmonauts' leisure hours, which included more than 110 spectator and music programs taken from among the best of the Soviet and foreign screen and stage. A total of 132 meetings were organized for the crews involving 121 representatives of different areas of public life: political reviewers, sports commentators, specialists, scientists, dramatic, film and variety artists who, being the logical source of information for the crews, often of a personal nature, also had a positive psychotherapeutic effect along the lines of deliberate regulation of the state of their emotional and motivational sphere, providing a high level of socialist motivation in the cosmonauts [10]: "... talks with families eliminated nervous stress and envigorated us for more than a day. After the 'meeting' with our families, we were ready to work without demanding rest around the clock" [11].

The efficacy of psychological support, along with other preventive measures, was confirmed both by the statements of the participants of long-term spaceflights and the results of medical monitoring of the cosmonauts' mental status and work capacity.

In summing up the results referable to the five main expeditions aboard Salyut-6, it must be stressed that man can not only adapt well to the unique habitat of a spacecraft, but work efficiently in it for long periods of time.

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CHANGES IN SOME RHEOLOGICAL PARAMETERS OF BLOOD IN EXPERIMENTS SIMULATING WEIGHTLESSNESS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 7 Dec 82) pp 25-30

[Article by A. P. Ivanov, I. B. Goncharov, A. F. Davydkin and V. I. Lavrov]

[English abstract from source] Changes in blood rheological parameters of 21 male volunteers, aged 25-37 years, were studied. The test subjects were subdivided into three groups. Nine subjects of Group 1 were exposed to head-down tilting (-8°) for 14 days, six subjects of Group 2 were exposed to 7-day continuous immersion, and six subjects of Group 3 to intermittent immersion. During head-down tilting the apparent viscosity and hematocrit and then caisson viscosity increased. By day 7 the coefficient of red blood cell aggregation decreased significantly. These changes persisted till the end of the tilt study. The above rheological parameters returned to normal three days after exposure. During continuous immersion the apparent viscosity showed the largest changes. Other specific changes included a moderate decrease of hematocrit, lack of significant changes in the yield limit of blood and a tendency towards an increase in the erythrocyte aggregation coefficient. Three days after the exposure the blood viscosity was much higher than before the study. During intermittent immersion rheological changes were induced by the first 36-hour exposure when shifts in blood viscosity and other parameters were most significant. It should be noted that following this exposure 72 hours of normal motor activity did not result in the normalization of the above rheological parameters.

[Text] It is a known fact that a number of pathological states associated with elevation of rheological parameters of blood are instrumental in onset of such complications as shock, thromboembolism and acute left ventricular insufficiency. Development of these complications is apparently directly related to blood viscosity [1-4], since increased viscosity could maintain hypoperfusion [5]. Moreover, a change in rheological properties of blood is also observed in the presence of stress situations. For example, some authors have noted the possible influence of stress on abrupt development of thrombosis and degree of myocardial necrosis [6, 7].

Degree and reversibility of erythrocyte aggregation, hematocrit, concentration of high-molecular plasma proteins, temperature and pH of blood [8-10] are the chief factors affecting blood viscosity. Properties of formed elements [11, 12] and condition of blood-clotting system [13-14] may have a substantial influence on viscosity of blood.

Clinical observations confirm the fact that, when the signs of disease are marked enough, there is always a combination of all or most of the rheological parameters of greatest importance, such as increased viscosity of plasma and whole blood, intensification of erytrhocyte aggregation and less deformability. This combination of four rheological parameters is referred to in the concept of "syndrome of increased viscosity" [2].

The acute period of adaptation to weightlessness during spaceflights is characterized by redistribution of fluid in the human body. Such redistribution results in elevation of central venous pressure, because of which there is stimulation of baroreceptors and volumoreceptors of the cardiovascular system, which leads to loss of body fluid. As a result of this loss, there is decrease in circulating blood volume, increase in blood concentration and, consequently, change in viscosity of blood, which is the main rheological parameter.

On the basis of the foregoing, it becomes obvious that investigation of rheological properties of blood under ground-based conditions with simulation of weightlessness is of great theoretical and practical interest, since the changes in rheological parameters of blood that are associated with most pathological states and variation of these parameters under the influence of spaceflight factors could aggravate any disease and increase the risk of such complications as shock, thromboembolism and acute left ventricular insufficiency. In addition, knowledge of the patterns of changes in rheological properties of blood could be of substantial relevance to development of programs of physical rehabilitation of cosmonauts.

Methods

Changes in some rheological parameters of blood were studied under ground-based conditions, with simulation of weightlessness, in essentially healthy men (21 people) 25 to 37 years of age, and for this purpose the subjects were divided into 3 groups. Those making up the first group (9 men) spent 14 days under strict bed rest conditions in antiorthostatic position (-8° tilt of head end of bed), i.e., under conditions of antiorthostatic hypokinesia (ANOH). The second group of subjects (6 men) were submitted to 7-day immersion by the method of unsupported "dry" submersion [15]. The third group of subjects (6 men) were submitted to intermittent immersion by the "dry" submersion method. The method of intermittent submersion consisted of the following: after 36 h of immersion the subjects spent 72 h on a schedule of usual physical activity. They were then submitted to 12-h immersion at night 3 times. The subsequent 12-h period of ordinary physical activity was followed by a final 36-h immersion.

Blood samples for determination of viscosity (in centipoise) and hematocrit (Ht, in %) were taken from the cubital vein. We also determined the parameters of caisson viscosity (K), range of blood fluidity (τ_0) and coefficient of red cell aggregation (A). Blood viscosity at three rates of change (0.5, 1 and 5 s^{-1}) was measured in the Zakharchenko rotating viscosimetric system at a temperature of 25±0.1°C.

Results and Discussion

Table 1 lists the rheological parameters of blood and hematocrit at different stages of ANOH.

Table 1. Changes in rheological parameters of blood and hematocrit during 14-day ANOH (M±m)

Time of examination	Blood viscosity (cp) at following rates (s^{-1})			K, cp	τ_0, dyne/cm^2	A, dyne/$cm^2 \times 10^{-6}$	Ht, %
	0.5	1	5				
Background	17.59 ±1.23	12.80 ±0.89	7.59 ±0.54	4.35 ±0.41	0.023 ±0.002	0.510 ±0.08	42.89 ±1.06
Third day of ANOH	25.26 ±1.24**	18.45 ±0.78**	10.40 ±0.46**	5.88 ±0.45	0.032 ±0.004	0.370 ±0.05	51.41 ±1.09**
Seventh day of ANOH	21.46 ±1.36**	16.16 ±0.98**	9.86 ±0.63**	6.24 ±0.55	0.024 ±0.003	0.260 ±0.04	50.24 ±1.56**
Fourteenth day "	28.46 ±2.25**	20.97 ±1.57**	12.88 ±0.83**	7.56 ±0.77*	0.033 0.004**	0.362 ±0.08	52.68 ±1.86**
Third day of recovery period	19.15 ±1.66	13.68 ±1.11	7.68 ±0.66	4.14 ±0.44	0.025 ±0.003	0.551 ±0.08	32.23 ±1.39

Note: Here and in Tables 2 and 3, one asterisk indicates $P<0.05$, as compared to base level (according to Student's t criterion), two asterisks indicate $P<0.01$, as compared to base level (also according to Student's t criterion)

The results indicate that there was reliable icnrease ($P<0.01$) in blood viscosity at all measured rates of shift on the 3d day of ANOH. Thus, blood viscosity increased by an average of 43.6% at a shift rate of 0.5 s^{-1}, by 43.02% at 1 s^{-1} and by 37.02% at 5 s^{-1}. Hematocrit increased by a mean of 19.80% on the 3d day of ANOH. The changes in other rheological parameters on the same day were unreliable. On the 7th day of ANOH, there was mainly increase in caisson viscosity of blood by an average of 43.45% and considerable decline of coefficient of erythrocyte aggregation (by 96.15%, as compared to base level). As for blood viscosity and hematocrit, they remained at the levels demonstrated on the 3d day of ANOH. On the 14th day of ANOH, the parameters of blood viscosity and hematocrit differed little from values of the 3d day. At the same time, blood viscosity was reliably greater than the analogous parameters on the 7th day of ANOH. The limit of blood fluidity was an average of 43.48% higher on the 14th day of ANOH than the base value. The indicator of caisson viscosity of blood was higher by an average of 73.79% than the base level, but did not differ from the value on the 7th day. On the 3d day of the recovery period, all of the tested parameters showed no difference from base values.

Thus, under ANOH conditions there were substantial deviations of rheological parameters of blood, manifested by successive changes. First of all, there was appreciable increase in viscosity of blood and hematocrit, and later caisson viscosity of blood. The changes in these parameters were associated

with considerable decline of the coefficient of erythrocyte aggregation by the 7th day of ANOH. Maximum change in these tests persisted in all subsequent days of ANOH. The parameter of fluidity of blood, which increased reliably only by the 14th day of ANOH, underwent the least change. On the 3d day of the recovery period all of the main rheological parameters reverted to the base values.

Table 2 lists the mean rheological parameters of blood and hematocrit at different stages of immersion.

Table 2. Changes in rheological parameters of blood and hematocrit with 7-day immersion

Time of examination	Viscosity (cp) at following rates (s^{-1})			K, cp	τ_0, dyne/cm^2	Λ, dyne/cm^2 x10^{-5}	Ht, %
	0.5	1	5				
Background	22.15 ±1.15	15.70 ±0.66	9.64 ±0.83	4.96 ±0.68	0.034 ±0.005	0.610 ±0.072	45.68 ±0.74
First day of ANOH	41.77 ±3.36**	31.46 ±2.61**	19.21 ±2.11**	12.75 ±2.15**	0.048 ±0.009	0.560 ±0.130	51.63 ±1.52**
Third day of ANOH	41.05 ±2.97**	31.96 ±2.56**	20.23 ±2.05**	14.72 ±1.80**	0.036 ±0.004	0.730 ±0.320	48.12 ±3.41
Seventh day of ANOH	49.84 ± 2.51**	39.49 ±2.57**	26.02 ±2.49**	18.20 ±2.17**	0.042 ±0.006	0.920 ±0.330	45.33 ±3.93
Third day of recovery period	31.84 ±1.67**	25.20 ±1.52**	16.56 ±1.34**	11.55 ±0.004**	0.028 ±0.062	0.470 ±1.80	46.08

The results indicate that there was considerable increase in blood viscosity already on the 1st day of immersion. Thus, with a shift rate of 0.5 s^{-1} this parameter rose by an average of 88.58%, at 1 m^{-1} [sic] by 100.38% and at 5 s^{-1} by 98.43%. The increase in caisson viscosity was also significant on the 1st day of immersion, constituting 157.06% of the base level. Hematocrit increased by an average of 13.03% on the 1st day of immersion. Changes in parameters of range of fluidity and caisson viscosity were unreliable. On the 3d day of immersion, all of the parameters showed virtually no difference from those recorded on the 1st day of immersion. The 7th day of immersion was characterized by further increase in blood viscosity and coefficient of erythrocyte aggregation. Conversely, hematocrit was relatively decreased. In the recovery period (3d day) blood viscosity and caisson viscosity did not decrease reliable at all shift rates, in comparison to the 7th day, but remained considerably higher than the base level. Thus, blood viscosity at a shift rate of 0.5 s^{-1} exceed the background value by an average of 43.55%, and at 1 and 5 s^{-1}, by 60.51 and 71.07%, respectively. The parameter of caisson viscosity of blood was higher by an average of 131.88% in the recovery period than the base level.

Thus, already 24 h after immersion, significant deviations were observed in rheological properties of blood. Maximum changes were detected in viscosity of blood at all measured shift rates, caisson viscosity of blood and hematocrit. On the 7th day there was some tendency toward increase in blood viscosity. We

should include among the distinctions of immersion the absence of appreciable changes in range of fluidity of blood, a tendency toward increase of the coefficient of erythrocyte aggregation and decline of hematocrit, against the background of high parameters for blood viscosity on the 3d and 7th days of immersion. Additional investigations are required to interpret this fact. However, we know from the literature that analogous changes in rheological parameters of blood are observed in the presence of ischemic heart disease. The increase in blood viscosity with drastic development of cardiac insufficiency is associated first with elevation of hematocrit (on the first 3 days) and then its decline. The high viscosity of whole blood after the hematocrit decline is attributable to increase in plasma viscosity and more intensive aggregation of erythrocytes [2]. Perhaps a correlation between the increase in blood viscosity with increase in plasma viscosity and more intensive aggregation of red blood cells will be demonstrated in future studies of the effect of immersion on man.

Table 3. Changes in rheological parameters of blood and hematocrit in the case of intermittent submersion

	Viscosity (cp) at following rates (s^{-1})			K, cp	τ_0, dyne/cm^2	A, dyne/$cm^2 \times 10^6$	Ht, %
	0.5	1	5				
Background	21.76 ±1.23	15.59 ±0.78	9.67 ±0.67	5.05 ±0.49	0.031 ±0.003	0.560 ±0.070	45.03 ±0.73
After 36-h submersion	35.89 ±3.02**	26.36 ±2.73**	16.12 ±2.60**	10.13 ±2.30**	0.039 ±0.004	0.380 ±0.060	54.70 ±1.56**
After 72 h of usual activity	28.55 ±2.03*	21.21 ±1.43*	13.26 ±1.19*	8.65 ±1.32	0.030 ±0.005	0.280 ±0.040	54.75 ±0.84
After 3-fold intermittent immersion	35.50 ±2.55**	26.14 ±2.57**	15.98 ±2.74**	12.09 ±3.21**	0.039 ±0.006	0.320 ±0.020**	55.77 ±2.50**
After 36-h immersion submersion	40.23 ±2.21**	29.48 ±2.26**	18.31 ±2.36**	11.71 ±2.19**	0.040 ±0.005	0.470 ±0.180	58.83 ±1.33**

Special mention must be made of the fact that blood viscosity on the 3d day of the recovery period, with use of immersion, was considerably greater than in the background.

Table 3 lists the average rheological parameters of blood and hematocrit in the case of intermittent immersion.

The data listed in Table 3 indicate that there was a reliable increase in viscosity of blood after 36 h of immersion. Thus, blood viscosity increased by an average of 64.93% at a shift rate of 0.5 s^{-1}, by 69.08% at 1 s^{-1} and by 66.70% at 5 s^{-1}. An increase in caisson viscosity of blood and hematocrit, by 105.90 and 21.47%, respectively, was also induced by 36-h immersion. The changes in parameters of range of fluidity of blood and coefficient of

red blood cell aggregation were unreliable after 36-h immersion. After 72 h of the usual physical activity, there was reliable decline of coefficient of erythrocyte aggregation by an average of 100%, as compared to the base level. The other rheological parameters only presented a tendency toward normalization. After 3-fold 12-h immersion, there was again elevation of rheological parameters in all 6 subjects, which was indicative of reliable ($P<0.01$ according to sign criterion) elevation of these parameters. At the same time, the coefficient of erythrocyte aggregation remained an average of 75% lower than the base level. The second 36-h immersion elicited further increase in blood viscosity and hematocrit. Thus, with shift rate of 0.5 s^{-1} blood viscosity was an average of 84.88% above the base level, at 1 s^{-1} it was 89.10% higher and at 5 s^{-1} 89.35% higher. The parameters of caisson viscosity of blood and hematocrit were an average of 131.88 and 30.65% higher, respectively, than the base levels. After 36-h of immersion, the parameters of range of fluidity of blood and coefficient of erythrocyte aggregation showed virtually no difference from base levels.

With the above-described conditions of immersion submersion, the changes in rheological parameters of blood were attributable to the effect of the first 36-h immersion, with which the most appreciable changes were demonstrated in viscosity and other parameters of blood. Less significant changes were observed in the case of 3-fold 12-h immersion. Changes in coefficient of erythrocyte aggregation presented the same pattern as with ANOH. It is important to note that 72-h rest did not lead to normalization of blood rheology.

The results of these studies revealed that, under ANOH and immersion conditions, some rather substantial changes occur in rheological properties of blood. The severity of such changes was at a maximum with immersion, after which the main rheological parameters were above background values, even on the 3d day of the recovery period. Since the above-described conditions simulate weightlessness, it can be expected that similar rheological changes will also occur in cosmonauts both during flights and in the recovery period.

The results are indicative of the need for further investigation of man's rheological parameters of blood, in both ground-based studies with simulation of weightlessness and during spaceflights. We believe that the results of future studies will make it possible to work out a set of measures for rendering medical care, improving its effectiveness, whereas correction of rheological disturbances would make it possible to prevent such dangerous complications as shock, thromboembolism and acute left ventricular insufficiency. In addition the obtained data could be of substantial relevance to development of programs for physical rehabilitation of cosmonauts.

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G SUIT OF BLADDERLESS TYPE AS A MEANS OF IMPROVING ORTHOSTATIC STABILITY AFTER WATER IMMERSION HYPOKINESIA AND EXPOSURE TO ACCELERATIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 26 Jan 83) pp 30-33

[Article by Ye. B. Shul'zhenko, V. G. Kozlova, K. A. Kudrin, A. S. Yarov and V. G. Plokhova]

[English abstract from source] Orthostatic tolerance after 7-day dry immersion and head-to-feet acceleration was investigated on test subjects with and without an antigravity suit of bladderless type. With the suit on, the 20 min tilt test at 70° prior to immersion induced less marked changes than without the suit. When the suit was on, cardiovascular reactions to tilt tests after immersion and acceleration improved. The maximum heart rate decreased from 105±4 to 101±5 beats/min ($p<0.01$), minimum stroke volume increased from 29±2 to 41±3 ml ($p<0.05$) and pulse pressure grew. Thus, an antigravity suit may help increase initial orthostatic tolerance and maintain it after the combined effect of simulated hypogravity and acceleration.

[Text] As a result of exposure to weightlessness or its models, there is a functional change in the body, development of "deconditioning," which is manifested in particular by impaired regulation of circulation in response to orthostatic tests [1-4]. The mechanism of this phenomenon has not been definitively identified. It is generally believed that the genesis of orthostatic disorders is based on a set of factors, including development of signs of dehydration of the body, change in neuroreflex mechanisms of regulating arterial and venous tonus, increase in capacity of the venous pool, decrease in muscle tone in the lower extremities and anterior abdominal wall [5-10]. All this is indicative of the desirability of using protective gear when cosmonauts return to earth's gravity.

Works have been encountered in the literature dealing with the effect on human orthostatic stability of pressure suits after both brief immersion in water (IM; 6-18 h) [11, 12] and bed rest [11, 13]. However, in these studies, orthostatic stability was tested right after simulated weightlessness, which does not correspond to actual flight conditions with accelerations during the spacecraft descent phase. There is sparse information about the effect of space [compensating] suits on orthostatic stability following actual

space flights. For this reason, we decided to test the effect of a G suit (GS) of the bladder-free type on man's orthostatic stability after exposure to a combination of simulated weightlessness and head-pelvis accelerations.

Methods

We simulated weightlessness by submerging the subjects by the dry immersion method for 7 days [6]. We conducted two series of tests involving the same subjects (6 people) 27-33 years of age. In the first series of tests (main series) the subjects wore GS and in the second series they did not (control series). We conducted a passive orthostatic test (70° angle) for 20 min before and after IM (1 h after exposure to accelerations with build-up gradient of 0.003 G/s to 5 G). We took the EKG in the Neba leads, measured blood pressure (PB) in the brachial artery according to Korotkov sounds in the 1st, 5th, 10th, 15th and 20th min of the orthostatic test. Stroke and minute volumes (SV, MV) were determined by tetrapolar rheography. Total peripheral resistance (TPR) was calculated using the Poiseuille formula.

During the orthostatic test we recorded the electromyogram (EMG) of the soleus muscle of the right and left leg.

The material was processed by Student's method of variation statistics.

Results and Discussion

During the orthostatic test with subjects who did not wear the GS, the heart rate increased by 36% after they moved to erect position in those wearing the GS the increment of this parameter constituted 16% (Figure 1a). However, in spite of the virtually identical decline of SV (percentage of level before changing position) in the 1st min in both series of tests, by the 20th min the subjects without GS demonstrated a decline of SV, while this parameter did not change appreciably in subjects who wore the GS (Figure 2a). The nature of change in MV resembled that of SV.

Pulse BP dropped by 42% in subjects who were not wearing a GS by the 15th min of the orthostatic test, whereas in those wearing the GS this parameter reverted to normal after dropping in the 1st min (Figure 3a). TPR was greater in the subjects with GS. In the 5th min of the orthostatic test following IM, the subjects without GS showed a 64% increase in HR [heart rate] by the 5th min, with virtually no change thereafter. Maximum HR constituted 135/min, versus 109/min before IM. In the series with use of GS, the HR increment constituted 36% and maximum HR 101/min, versus 85/min before IM (Figure 1b). In these studies, we also used the mean pulse rate in the last 5 min of the orthostatic test, which is a more reliable means of assessing orthostatic stability [14-15]. We found a decline of this parameter with use of GS both before IM (by 21%) and after (by 26%). SV dropped by 38% in the control series, in the 1st min after moving the body from horizontal to vertical position. In the main series, this decline constituted 30% and, in the course of the orthostatic test, we observed a tendency toward relative increase of SV (Figure 2b). The results of analysis of changes in MV during the orthostatic test did not enable us to demonstrate an appreciable difference between the two series; however, after IM, MV value was lower in subjects without GS than before IM. With use of GS, the reverse

was observed. In both the main and control groups, there was a 20% drop of pulse pressure after moving from horizontal to vertical position (Figure 3b). However, it should be noted that, when wearing the GS during the orthostatic test, pulse pressure held at a constant level, whereas in the control series there was a tendency toward further decline. No appreciable changes were demonstrated in TPR in both series of studies during the post-IM orthostatic tests.

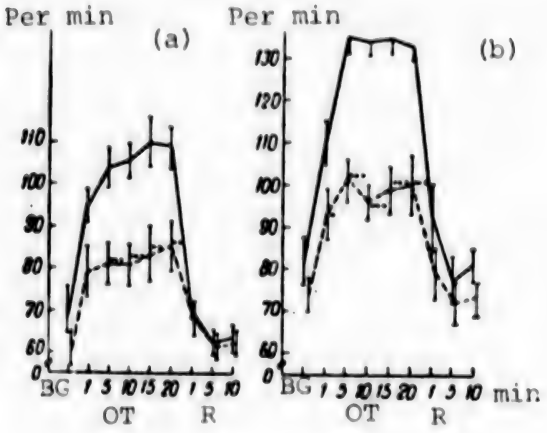

Figure 1.
HR response to orthostatic test
Here and in Figures 2 and 3:
a) before immersion
b) after immersion
Solid line--no GS
Dash line--wearing GS
*P<0.05
**P<0.02
***P<0.01, as compared to parameters without wearing GS

BG) background
OT) orthostatic test
R) recovery

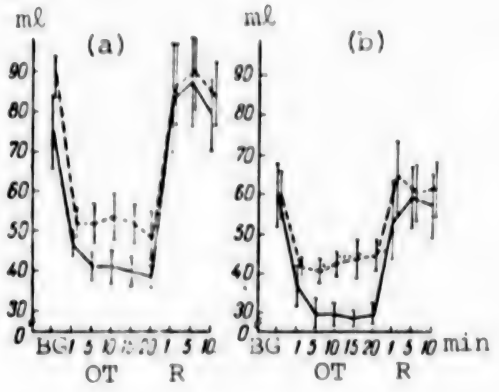

Figure 2.
SV value during orthostatic test

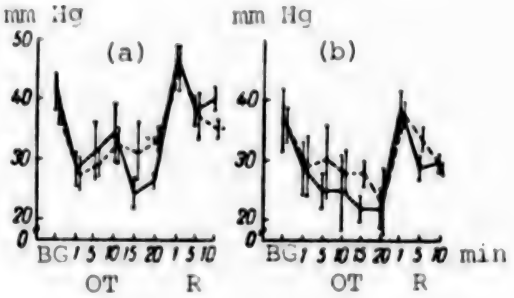

Figure 3.
Pulsed BP change during orthostatic test

A comparative analysis of changes in recorded parameters revealed that HR was reliably lower in subjects wearing the GS while SV was higher. No reliable differences were demonstrable in changes in MV in the two series. However, MV was maintained by somewhat different means in the first and second series of tests. In the control series, there was a more marked decline of SV and corresponding rise of HR. Moreover, there was less difference in the first series between values of HR and SV during orthostatic tests performed before and after IM (see Figures 1 and 2).

The above-described hemodynamic changes during the orthostatic test occurred against a background of marked bioelectrical activity of the soleus muscles. Wearing the GS caused retention of the initial level of bioelectrical activity during the 20-min test. At the same time, in subjects without GS, the level

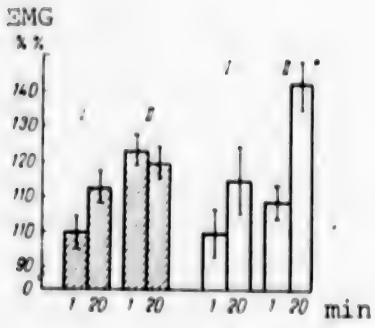

Figure 4.
Change in mean amplitude of soleus EMG during orthostatic test (1st and 20th min)
100%--EMG in 1st min of orthostatic test before IM
Hatched bars--wearing GS
White bars--without GS
I) before IM
II) after IM

of the EMG of the soleus muscles rose by 30% during post-IM orthostatic tests on subjects without the GS (Figure 4). In addition, performance of the orthostatic test without using a GS was associated with signs of synchronization, a tendency toward grouping of EMG waves, which was indicative of development of fatigue and decrease in electromechanical efficiency of muscular contraction [16,17].

Thus, using of GS in tests with IM is an effective means of protection, and this conforms to data in the literature [11, 12].

At the present time, there is prevalence of the conception of redistribution of blood with the body in orthostatic position [1, 2, 18, 19], which is associated with deposition of a certain amount of blood (300-800 mℓ) in the lower half of the body, decrease in central blood volume and reduction of venous return to the heart. Functional integrity of the reaction of the cardiovascular system to change to vertical position is provided by a complicated set of physiological mechanisms, in particular, increased activity of the adrenosympathetic system as a result of attenuation of depressor influences from baroreceptors of carotid sinuses and the aortic arch. This is associated with faster heart rate, as well as reflex increase in tonus of capacitance vessels and peripheral arteries, which causes decrease in capacity of the venous pool in the lower half of the body and causes adequate distribution of cardiac output.

In addition to deposition of blood due to earth's gravity, shifting of fluid in the extravascular space of the lower extremities as a result of elevation of capillary filtration pressure is also important [19]. Worsening of compensatory capabilities of the cardiovascular system with regard to gravity leads to a so-called vasodepressor reaction, which is caused by increased activity of the parasympathetic nervous system [8, 13].

As noted above, there is an entire set of different factors in the genesis of orthostatic disorders after simulated and real weightlessness. A special place is ascribed to intensification of the tendency to deposit venous blood when changing to upright position [8]. Expressly this determines the desirability of using GS to increase orthostatic stability.

The GS, which exerts excess pressure on the lower extremities and abdominal wall, causes a decrease in capacity of the venous system in these regions and, consequently, prevents deposition of blood. Elevation of intratissular pressure also leads to decreased filtration of the liquid part of blood from the vascular system to the extravascular space. Moreover, excess exogenous pressure elicits shifting of blood in a cranial direction, i.e., causes its centralization.

In our tests, data were also obtained that are indicative of retention of muscle tone and prevention of development of muscular fatigue with use of the GS. It is known that activation of the muscle pump is an important mechanism for increasing venous return.

All this creates conditions for maintaining the level of circulation at the required level in the upper part of the human body.

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STUDY OF METABOLIC SEQUELAE OF USING POSITIVE INTRAPULMONARY PRESSURE DURING EXPOSURE TO ACCELERATIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 19 Nov 82) pp 33-36

[Article by J. Domaczuk (Polish People's Republic)]

[English abstract from source] The purpose of this study was to identify metabolic changes in pilots exposed to linear acceleration with an onset rate of 0.1 G/sec. The exposure to +Gz increased the content of lactate dehydrogenase and the concentration of lactate dehydrogenase and the concentration of potassium and phosphorus in plasma. Positive pressure breathing of 60 hPa during acceleration enhanced its tolerance by 2.2 G, producing no effect on metabolic changes.

[Text] Our studies revealed that excess intrapulmonary pressure (EIP) has a beneficial effect on tolerance of +Gz accelerations. Under the influence of EIP, pilots reached greater accelerations. We also found that EIP had a beneficial effect on the reaction of the blood system during exposure to accelerations. It was established that 60 HPa is the optimum EIP for enhancing tolerance of +Gz accelerations.

Exposure to +Gz accelerations elicits a number of reactions and, in particular, hemodynamic disorders. The latter are associated with metabolic changes, the extent of which is essentially proportionate to the magnitude of accelerations [1-3].

It is known that EIP elicits impairment of circulation, while the associated metabolic changes are in a range that is similar to the one associated with exposure to accelerations [4-6].

It was deemed desirable to investigate whether the metabolic disorders associated with positive pressure breathing reach critical levels, since it has been reported that the combination of accelerations and EIP could have a synergistic effect.

Methods

We conducted the tests on a centrifuge with an arm 9.5 m in length, with the participation of pilots who were divided into 2 groups of 15 people each. Pilot tolerance of +Gz accelerations was determined using a linear program of increasing accelerations at the rate of 0.1 G/s. Narrowing of the visual field (blackout) was the criterion of tolerance of accelerations. The pilot was in a closed cabin, sitting down, and submitted to rotation until he blacked out. The acceleration that elicited a blackout was considered the maximum endurable level for the subjects.

In the first group of subjects, who served as a control, we tested tolerance of accelerations by the standard method; in the second group we used constant EIP of 60 GPa. In the latter case, the subjects wore altitude-compensating suits and helmets. The unit installed in the centrifuge cabin created EIP of 60 GPa for the period from the start to stop of the centrifuge. Air was delivered inside the pressure helmet, from which the pilot breathed. Compensating pressure affecting the entire body (with the exception of the palms of the hands and feet) corresponded to EIP. A G suit was not used.

The metabolic sequelae of exposure to accelerations (first group) as well as of combined exposure to accelerations and EIP (second group) were assessed on the basis of analyzing venous blood, which was taken from all pilots before rotation and right after it. We assayed blood serum chlorine, potassium, sodium, calcium, phosphorus, urea, uric acid, glucose, lactate dehydrogenase (LDH), lactic acid, pyruvic acid, total protein and albumins. For these tests, we used SMA-6 and SMA-12 automatic analyzers. The enzymatic method was used to assay lactic and pyruvic acids. Statistical evaluation was made by the method of Student.

Results and Discussion

The parameter under study constituted 6.4±0.81 G for the first group of pilots and 8.6±1.26 G for the second. The differences between results were statistically reliable ($P<0.01$).

Table 1 lists the results of biochemical blood tests on subjects in the first and second groups. This table shows that accelerations elicit elevation of levels of glucose, lactic and pyruvic acids, as well as increase in activity of LDH and decrease in potassium and phosphorus content of blood serum in the first group of subjects. They showed no change in other tested biochemical parameters of blood in the course of the study.

In the second group of subjects, exposure to the combination of accelerations and EIP elicited changes that were similar to those in the first group, with respect to levels of glucose, lactic and pyruvic acids, as well as increase in LDH activity and decrease in blood serum potassium and phosphorus. The rest of the biochemical parameters of blood did not change in the course of the study.

Table 2 lists the comparative results of biochemical blood tests on the two groups of pilots. It lists only the parameters that underwent appreciable changes during the experiment. As we see from Table 2, the degree of change

in some biochemical parameters of blood in the second group of pilots did not differ statistically from analogous data for pilots in the first group.

Table 1. Changes in biochemical parameters of blood after determination of tolerance of +Gz accelerations on a linear program in first and second groups of subjects (M±m)

Blood parameter	Unit of measurement	First group		Second group	
		before rotation	after rotation	before rotation	after rotation
Chlorine	mmol/ℓ	106±8.4	103±11.7	103±12.1	100±8.3
Potassium	"	4.47±0.21	4.17±0.30*	5.2±0.30	4.7±0.22*
Sodium	"	142±11.8	143±14.0	146±12.7	145±10.8
Phosphorus	"	1.13±0.06	1.03±0.07*	1.43±0.07	1.32±0.08*
Calcium	"	2.52±0.26	2.53±0.18	2.45±0.10	2.55±0.11
Protein	g/ℓ	78±1.3	79±1.1	79±5.5	81±4.8
Albumins	μmol/ℓ	695±29.0	695±31.9	689±44.9	695±53.6
Glucose	mmol/ℓ	5.77±1.01	6.83±0.87*	5.60±0.46	7.17±0.35*
LDH	IU	167±18.2	202±23.6*	182±22.5	211±20.7*
Lactic acid	mmol/ℓ	1.12±0.08	1.80±0.14*	1.14±0.09	1.98±0.14*
Pyruvic acid	μmol/ℓ	58.2±15.9	86.6±21.7*	52.4±13.6	80.8±18.2*
Uric acid	"	36.3±3.1	35.1±2.74	34.5±1.96	33.9±1.46
Urea	mmol/ℓ	97.8±7.4	110±16.5	93.1±8.52	88.2±7.80

* $P < 0.01$

Table 2. Comparative changes in biochemical parameters in determining tolerance of +Gz accelerations on a linear program in first and second groups of subjects

Blood parameter	Unit of measurement	Degree of change	
		first group	second group
Potassium	mmol/ℓ	−0.30±0.28	−0.51±0.25
Phosphorus	"	−0.10±0.04	−0.11±0.05
Glucose	"	1.06±0.46	1.57±0.57
LDH	IU	35±21.5	29±19.4
Lactic acid	mmol/ℓ	0.68±0.22	0.84±0.24
Pyruvic acid	μmol/ℓ	28.4±17.0	37.5±10.4

Under the conditions of our tests, metabolic processes occurred at a low oxygen content [1-3, 5, 7]. In addition, accelerations and EIP elicited stress reactions [8-10].

Breakdown of glucose in the presence of low oxygen content occurred primarily due to anaerobic glycolysis with discharge into blood of acid products of carbohydrate metabolism. For this reason, after rotation the pilots showed a high level of lactic and pyruvic acids, as well as increased LDH activity. These changes were observed in both groups of subjects and they were quantitatively the same, regardless of use of EIP.

Acidulation of the medium, as well as the high hydrostatic pressure gradient in the vascular system during exposure to accelerations, elicit changes in permeability of vessels and cell membranes [1-13]. After rotation, we demonstrated only a decline of phosphorus and potassium levels in blood serum. Quantitatively, these changes did not differ in subjects of the two groups. Elevation of lactic acid and pyruvic acid levels, as well as decline of blood serum potassium, were more marked in the second group of pilots than the first. However, the differences were unreliable. Use of EIP during exposure to accelerations supplemented compensatory mechanisms of the circulatory system, so that resistance to accelerations increased. This could explain why the rise in threshold of resistance to accelerations had no appreciable effect on biochemical parameters of blood.

Thus, use of EIP of 60 GPa improves significantly tolerance of +Gz accelerations and has no additional effect on the level of metabolic processes.

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EFFECT OF SYDNOCARB ON HEMODYNAMICS AND REDISTRIBUTION OF BLOOD DURING FUNCTIONAL TESTS FOLLOWING SIX-HOUR ANTIORTHOSTATIC HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 1 Feb 83) pp 36-39

[Article by A. Yu. Modin, S. V. Abrosimov, G. V. Amel'kina, O. D. Anashkin, V. V. Zhidkov, V. I. Lobachik, L. B. Parshin and V. S. Shashkov]

[English abstract from source] Man's orthostatic tolerance and physical work capacity declined in response to 6-hour head-down tilt at -15°. During tilt tests heart rate increased, blood pressure fell, and blood pooling in the upper body decreased. During exercise tests the circulating blood volume, total amount of the work performed, and consumed oxygen decreased. Sydnocarb given at a dose of 25 mg during head-down tilt did not influence the circulating blood volume and oxygen consumption. All other parameters varied approaching the pretest values.

[Text] Mainly agents that have a physical effect on the body are used in modern space medicine to prevent orhtostatic disturbances and preserve work capacity [1]. There are only a few publications [2-5], in which there are indications of the prospects of using drugs in order to preserve work capacity and orthostatic stability.

Our objective here was to assess the effect of sydnocarb on hemodynamics and redistribution of blood in the human blood stream following 6 hours of anti-orthostatic [head tilted down] hypokinesia (ANOH) during functional load tests.

Methods

A total of 8 essentially healthy men 30-39 years of age participated in 3 series of tests conducted at intervals of at least 14 days at the hospital.

In the first series (control), all of the subjects were on the usual regimen, in the second and third series they spent 6 h in antiorthostatic position, with a tilt of -15°, prior to the functional test. In the second series, the subjects were given placebo 30 min before and in the 3d and 5th hours of hypokinesia; in the third series, they were given sydnocarb at the same times, in doses of 5 mg before and 10 mg during ANOH.

In all of the series, the orthostatic test was conducted with an angle of inclination of +75°, as well as a maximum physical load test (MPL). Physical work capacity was determined on a bicycle ergometer, starting with 450 kg-m/min with subsequent increase by 150 kg-m/min every 3 min until the subject was completely tired.

We recorded the EKG continuously for determination of heart rate (HR). Blood pressure (BP) was discretely measured with an automatic AVM-4 type gauge (Hungarian People's Republic). Oxygen uptake was recorded on a Spyrolit (GDR) gas analyzer. Redistribution of circulating blood during orthostatic tests was determined using a special stand, which made possible simultaneous radiometry of the entire human body and different parts (head, chest, abdomen, lower limbs), with subsequent computer processing and output of results as percentage of overall circulating blood in the body. We used ^{113m}In in a dosage of 17.5 mBq (0.26 mBq/kg body weight) as the radiotracer. We determined the volume of circulating plasma (CPV) according to dilution of radioactive ^{131}I-labeled human serum albumin, which was injected intravenously in a dosage of 0.18 to 0.37 mBq. Circulating blood volume (CBV) was determined using the formula:

$$CBV = \frac{CPV \cdot 100}{100 - H \cdot 0.9}$$

where H is venous blood hematocrit and 0.9 is the coefficient for calculating hematocrit of the entire body [6]. Venous blood hematocrit was determined using a microhematocrit centrifuge turning at 8000 r/min for 5 min. Circulating red blood cell volume (CRBV) was determined as the difference between CBV and CPV.

The volume of blood taken for the radiometric test was made up with isotonic NaCl solution.

Statistical processing was performed by the method of comparing in pairs the individual data for each parameter in the first and second, and in the second and third series.

Results and Discussion

One of the subjects demonstrated a collaptoid reaction in the 20th, 4th and 12th min of the orthostatic test in the first, second and third series, respectively. In the second series, an analogous reaction was recorded in the 19th min for a subject who endured satisfactorily the orthostatic loads in the first and third series. The rest of the subjects endured well 20-min in orthostatic position in all three series of tests.

During the orthostatic test, maximum HR increased reliably by an average of 7/min in the second series and decreased reliably by a mean of 4/min in the third series. As a result of ANOH, both systolic and diastolic BP dropped by an average of 5 mm Hg during the orthostatic test. Intake of sydnocarb prevented the tendency toward postural hypotension, systolic BP rising reliably by 8 mm Hg and diastolic by 10 mm Hg ($P<0.01$).

Analysis of radiometric data referable to the entire body impressed us by the tendency toward caudal distribution of circulating blood in the second series at the end of ANOH, in clinostatic and orthostatic positions (Table 1). Distribution of blood in the third series was generally the same in nature as in the first.

Table 1. Distribution of circulating blood over different parts of the body (% of CBV) during postural tests

Position	Part of body	Series		
		I	II	III
Antiorthostatic position	Head and neck	12.37	11.46*	12.08
	Chest	40.02	38.77	40.50**
	Abdominal organs	30.43	31.35	29.81
	Lower extremities	17.17	18.33*	17.52**
Horizontal	Head and neck	11.93	10.72*	11.41
	Chest	37.73	36.30	38.15**
	Abdominal organs	30.93	32.78*	30.57
	Lower extremities	19.30	20.08	19.79
10th min orthostatic test	Head and neck	9.36	9.43	9.32
	Chest	26.39	24.53*	26.34**
	Abdominal organs	33.16	33.56	32.49
	Lower extremities	31.00	32.41*	31.76**
20th min orthostatic test	Head and neck	9.54	9.23	9.13
	Chest	25.43	24.02	26.37**
	Abdominal organs	33.31	34.40	33.07
	Lower extremities	31.64	32.28	31.37

*$P<0.05$, when comparing individual data on the subjects.
**$P<0.05$, when comparing individual data for subjects in the second and third series

Table 2. Volumes of circulating blood, plasma and erythrocytes (mℓ/kg) during functional tests

Series	Parameter	Before ortho test	Ortho test		Before MPL	After MPL
			10th min	20th min		
I	CBV	79.51	78.37	74.86	78.73	74.25
	CPV	48.32	43.72	41.09	44.77	39.53
	CRBV	31.19	34.55	33.77	33.96	34.72
II	CBV	75.79	75.89	72.27	71.00	68.88
	CPV	44.06	42.70	40.56	40.53	37.17
	CRBV	31.73	33.19	31.71	30.47	31.71
III	CBV	75.44	73.62	73.12	75.72	70.83
	CPV	43.73	40.66	40.24	42.42	38.51
	CRBV	31.71	32.96	32.88	33.30	32.32

The results listed in Table 2 indicate that there was a decrease in CBV and CPV by 5 and 9%, respectively, under the effect of 6-h ANOH. An analogous change in CBV and CPV was noted in the third series of tests, which shows that sydnocarb had no effect on these parameters, while their decline in this series was attributable to ANOH.

In all of the series, the orthostatic tests were associated with a reliable decrease in CPV by 15, 8 and 8% in the first, second and third series, respectively. There was concurrently a tendency toward increase in CRBV, which was more marked in the 10th min of the test. This parameter rose in all subjects but one in the first series, there was an insignificant decline in half the cases in the second series and increase of CRBV in the other half; in the third series, this parameter rose in 6 subjects and dropped in 2. CBV decreased unreliably in all series during the orthostatic test.

After maximum physical load, we also observed a tendency toward decline of CBV and CPV, the change in the latter parameter being reliable in the first and second series.

As can be seen in Table 3, there was reliable 16% decrease in overall volume of performed exercise, 10% decrease in maximum oxygen uptake (MOU) and 10% decrease in oxygen pulse (OP). With intake of sydnocarb, exercise time and volume on the bicycle ergometer increased in 5 subjects, did not change in 2 and decreased in 1. The volume of exercise performed in the third series increased by an average of 8%, MOU and OP showed virtually no change.

Table 3. Overall volume of performed exercise and parameters of cardiorespiratory system with MPL

Series	Exercise time	Total work vol, kg-m/kg	Maximum HR/min	MOU, ml/min	OP, ml (beats·min)
I	16 min 42 s	173	180.4	3002	16.7
II	14 " 46 s*	145*	177.9	2698*	15.2*
III	15 " 38 s	157	181.5	2722	15.0

*$P<0.05$, in comparing individual values for the same parameters in the first and second series of tests.

Thus, proceeding from the generally held thesis that greater increases in HR and decreases in BP are integrative indicators of deadaptation of the circulatory system for orthostatic loads [7] and considering the obtained results and clinical findings, it can be assumed that a man's condition after 6 h of ANOH at a tilt angle of -15° reproduces rather completely the set of symptoms of orthostatic instability.

The demonstrated decline of CPV (in the range of 9%) during ANOH differs insignificantly from results obtained by other researchers [8], who studied plasma loss during immersion in water of the same duration. Sydnocarb, which was given during hypokinesia, had no effect on CBV and CPV. The migration of liquid part of blood from the blood stream in the lower limbs under the influence of elevated hydrostatic pressure should be viewed as the cause of CPV decrease during the orthostatic test. It should be noted that the same amount of plasma exited from the blood stream in the second and third series during orthostatic tests, and it was less than in the first series.

The increase in CRBV during the orthostatic tests is probably attributable to exit of erythrocytes from their pool. This tendency was more marked in the

first series of studies. There was an insignificant difference between the second and third series in values of CRBV during orthostatic tests, although there was more consistent increase when sydnocarb was taken.

The relative decrease in amount of circulating blood in the region of the head and upper body in the second series, in antiorthostatic, horizontal and upright positions is apparently due to compensatory vascular reactions that occurred during the preceding antiorthostatic conditions. There is information [9] to the effect that, during brief antiorthostatic position, passive mechanical filling of cerebral vessels causes their constriction when the gravity component in the direction of the body's longitudinal axis equals 0.3-0.4 G. In our studies a tilt angle of -15° provided for 0.26 G in the direction of the body's longitudinal axis. Probably, 6-h ANOH was sufficient for manifestation of vasoconstrictive reactions at lower levels of hydrostatic pressure in the vascular pools of the head than the threshold. The relatively smaller amount of blood in the upper part of the body and relatively larger amount in the lower part during orhtostatic tests was apparently instrumental in worsening orthostatic stability of the subjects in the second series.

The effect of sydnocarb on distribution of CBV in different parts of the body during all postural tests consisted of reliable increase in intrathoracic blood volume and general tendency toward cranial shift of blood. Since CBV was virtually the same in the second and third series, dependence of distribution of blood on the volemia factor is unlikely, while the fact that experimental conditions were identical indicates that the distribution of blood in subjects of the third series was the result of pharmacodynamics of sydnocarb. It is known [10] that sydnocarb, which is an indirect sympathomimetic, facilitates release of norepinephrine by nerve endings of postganglionic sympathetic fibers. We view this as the cause of BP elevation during the orthostatic tests in the third series of studies. Since norepinephrine is also involved in reflex constriction of veins, we cannot rule out a venotonic effect from the pharmacodynamic spectrum of sydnocarb. Finally, we do not know which sections of the arterial system are predominantly affected by this drug and, consequently, it is not clear how the distribution of cardiac output changes among the different vascular pools of the arterial system when it is prescribed.

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RESPIRATORY TRACT 'CLOSING VOLUME' AND STRUCTURE OF TOTAL LUNG CAPACITY DURING SEVEN-DAY HYPOKINESIA IN HEAD-DOWN POSITION

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[Article by E. M. Nikolayenko, V. Ye. Katkov, S. V. Gvozdev, V. V. Chestukhin, M. I. Volkova and M. I. Berkovskaya]

[English abstract from source] By mass spectrography and pneumotachography structural variations in total lung capacity (TLC) were investigated in 7 test subjects during 7-day head-down tilt at -15°. By the 7th hour of head-down tilt TLC, vital lung capacity (VLC), functional residual capacity (FRC) and residual volume (RV) decreased significantly and closing volume (CV) increased insignificantly. The CV/FRC ratio grew from 0.82±0.03 to 1.24±0.08 ($P<0.01$), indicating the closure of respiratory pathways in certain lung structures within the tidal volume. These changes in the TLC structure persisted till day 7 but the CV/FRC ratio fell down to 1.01±0.07. The above findings can clarify the mechanism responsible for a lower oxygenation of arterial blood in the head-down position. The expiratory closure of the airways within the tidal volume causes regional changes in alveolar ventilation and ventilation-perfusion relations and, consequently, a larger venous admixture and a smaller oxygen saturation of arterial blood.

[Text] The influence of changes in vector and force of gravity on respiration has been discussed in a number of works by Soviet and foreign researchers [1-6], but the mechanisms of impairment of gas exchange and adaptation of human pulmonary functions to weightlessness and accelerations have not been sufficiently studied. Investigation of the functional state of the small respiratory airways (SRA), which play an important part in distributing inspired air and maintaining effective exchange of gases, is a new approach to the study of these questions. However, it is not in vain that Mead [7] called the SRA the "silent zone" of the lungs, for evaluation of SRA function in man involves some serious methodological difficulties. Recently, the curve of forced expiration and the method of measuring the lung "closed volume" (CV) started to be used for such evaluation.

In order to study the mechanisms of impairment of pulmonary exchange of gases in weightlessness, our objective here was to observe the structural dynamics of total lung capacity, volume and capacity of closure of respiratory pathways during 7-day antiorthostatic [with head tilted down] hypokinesia (ANOH at an angle of -15°).

Methods

This study was conducted on 7 healthy males whose average age was 33.3±5.2 years, with 178±6 cm height and 75.1±10.2 kg weight. Gas flow rate ($\dot{V}$) and respiratory volumes (V) were measured with a pneumotachograph (PTG) and heated Fleish No 4 head (Godart). An RMS-BG (Godart) mass spectrograph was used to measure gas (F_{N_2}, O_2, CO_2, Ar) concentration in breathing mixtures. All of the measured parameters were written down in analogue form on a six-channel BRUSH-206 (Godart) recorder, stored in an RDR analogue-digital computer (ADC) or reproduced on a Tetronix display in digital and graphic form. Lung volumes were scaled to BTPS.

During the study, the subject breathed atmospheric air through a mouthpiece and three-way valve (Figure 1) for 1-3 min until there was stabilization of P_AO_2, P_ACO_2 and ventilation level. Functional residual capacity (FRC) and residual volume (RV) of the lungs were measured by the method of single expiration, according to nitrogen and argon dilution simultaneously. After a complete expiration into the atmosphere to the RV level, the three-way valve was switched to a bag containing about 2 ℓ 10% mixture of Ar in oxygen, the subject took a quiet breath of this mixture and then made a full expiration (exact volume of inhaled gas was recorded on the PTG). RV was calculated on the basis of the measured alveolar concentrations of N_2 and Ar using the following formulas:

$$\text{RV } (N_2) = \frac{F_EN_2 \cdot V_1 - F_AN_2 \cdot V_D}{F_AN_2 - F_EN_2};$$

$$\text{RV } (Ar) = \frac{F_1Ar\,(V_1 - V_D)}{F_EAr} - V_1,$$

where F_EN_2, F_EAr is concentration of N_2 or Ar in exhaled air, F_AN_2 is alveolar concentration of N_2 before inspiration of O_2, F_1Ar is concentration of Ar in tracer mixture, V_1 is volume of inhaled mixture, V_D is total volume of dead space (according to Bohr) and instrument space.

Vital capacity of the lungs (VC) was measured at maximum inspiration and expiration, and we took into consideration only the readings, in which inspiratory and expiratory VC did not differ by more than 5%. CV was measured with two methods simultaneously: residual ["resident"?] [8] and bolus [9]. We determined the start of expiratory closure of the airways from the point of transition of the 3d phase on the expiratory curve to the 3d phase (Figure 1B). In this study, we used in the measuring system a Fleish head No 1 and special resistor, which helped maintain a slow rate of expiration, which is a mandatory

prerequisite for this test. After a complete expiration into the atmosphere, the valve was switched to a 2-bag system with 50 mℓ Ar in the small one and pure oxygen in the large one. The subject took a complete breath in such a way as to first inhale Ar, then O_2 and started expiration without delay. The subject checked the rate of expiration, 0.2 $\ell \cdot s^{-1}$, himself on a needle indicator.

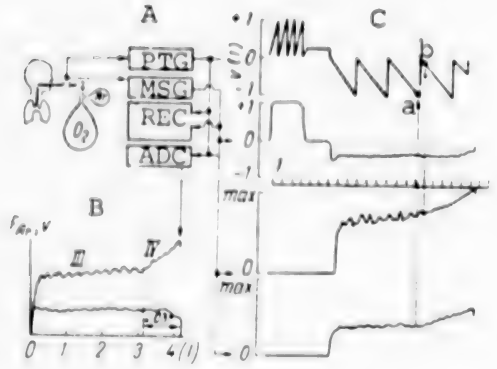

Figure 1.
Diagram of methodological system (A) and examples of tracings on computer display (B) and recorder (C)
A) PTG--Godard pneumotachograph
MSG--Godart PMS-BG mass spectrograph
REC--6-channel BRUSH recorder
ADC--analogue-digital PDP-8a computer
B) x-axis, volume of exhaled gas (ℓ); y-axis, concentration of Ar (top curve) and rate of expiration (bottom curve)
III, IV) third and fourth phases of expiratory curve; arrowhead shows volume at which expiratory closure of airways begins
C) top to bottom: volume of inhaled and exhaled gases (ℓ); gas flow rate ($\ell \cdot s^{-1}$), time mark 1 s, concentration of Ar, concentration of N_2

During the test we recorded curves from which calculations were made (see Figure 1). The first and second phases of expiratory curves for N_2 and Ar correspond to uptake of gases from the dead space; the third phase reflects the alveolar concentration of these gases; the move to the fourth phase is characterized by a distinct increase in slope of the concentration curve. Such an increase in alveolar F_{Ar} and F_{N_2} is related to the fact that passage of gases from underlying parts of the lungs diminishes or stops due to closure of the airways.

The difference between Ar and N_2 concentrations in the upper and lower alveoli is attributable to the vertical differences in pressure and regional RV [10]. The bottom alveoli, which are more compressed and closed at the start of inspiration from the RV level do not receive Ar (or else receive much less), the concentration of which is higher in the upper alveoli. For this reason, the moment when there is an abrupt increase of F_AAr on the expiratory curve is indicative of the start of closure of the lower alveoli.

Regional alveolar concentrations of N_2 after maximum inspiration of oxygen depend on the ratio of regional preinspiratory lung volume to volume of O_2 entering this zone [11]. The higher this ration, the higher the F_AN_2. For this reason, the concentration of N_2 in the upper alveoli is higher and the time of deflection of the expiratory curve upward from the alveolar plateau corresponds, just like on the argon curve, to the start of closure of the airways. We find the closing capacity (CC) as the sum of RV and CV.

All calculations and statistical processing were performed using special proggrams on a PDP-8a analogue-digital computer ("DIGITAL").

Results and Discussion

Total lung capacity (TLC) immediately after changing from horizontal to -15° ANOH position dropped by an average from 6.62±0.2 to 6.39±0.18 ℓ. By the 7th h, TLC dropped to 5.89±0.16 ℓ ($P<0.05$) and held at this level to the 3d day. On the 7th h of ANOH we observed an increase in TLC in 6 subjects out of 7; TLC constituted a mean of 6.25±0.14 ℓ.

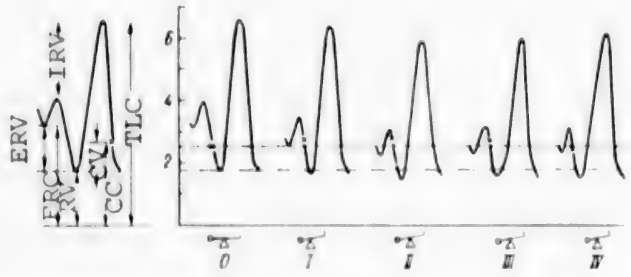

Figure 2.
Dynamics in structural changes in TLC. Components of TLC shown on left. X-axis, here and in Figure 3, stages of study:
0) horizontal position
I) 30-40 min ANOH -15°
II) 7th h of ANOH -15°
III) 3d day of ANOH -15°
IV) 7th day of ANOH -15°
Y-axis, here and Figure 3: volume (in ℓ BTPS); dash line shows base level of CC; dot-dash line shows initial level of RV, × shows volume at which expiratory airway closure begins

Such changes in TLC were due to decline of both VC and RV (see Table and Figure 2), which decreased appreciably by the 7th h of ANOH ($P<0.02$). Thereafter, VC had a tendency toward increase while RV, which had dropped from 1.8±0.11 in horizontal position to 1.54±0.11 ℓ by the 7th h in tilted position, held at this level to the end of the test, 1.55±0.12 ℓ on the 7th day. The RV percentile fraction of TLC changed little during ANOH, as compared to the base value, remaining close to 27% and dropped to 24.8% only on the 7th day.

The most remarkable changes were referable to FRC and CC of the lungs, which are shown in Figure 3 and the Table. Right after the subjects were moved from horizontal to tilt position at an angle of -15°, their FRC declined from 3.13±0.07 to 2.51±0.16 ℓ ($P<0.05$), while CC increased insignficantly (from 2.57±0.11 to 2.66±0.09 ℓ). By the 7th h these changes became more defined: FRC = 2.3±0.17 ℓ, CC = 2.78±0.11 ℓ, and on the 3d day FRC and CC held at about the same levels (2.4±0.13 and 2.63±0.1 ℓ, respectively), whereas by the 7th day there was increase in FRC to 2.41±0.16 ℓ and decrease in CC to 2.44±0.08 ℓ, but these parameters did not reach the values demonstrated in horizontal position. Expiratory reserve volume, ERV, decreased in accordance with the changes in FRC and RV (see Figure 2 and the Table).

Lung capacities and volumes decreased more at -15° ANOH than -4° [3] or with submersion in water [12], although there was an analogous tendency toward changes in TLC structure. Unquestionably, the most significant of these changes was the decline of ventilation level, i.e., decrease in ERV and FRC. Several years ago, Nunn et al. [13] showed that breathing air at the level of maximum voluntary reduction of lung volume leads to decreased oxygenation of arterial blood. An analogous drop of P_aO_2 and elevation of $\Delta P_{A-a}O_2$ was noted in our studies and those of other authors [2, 14].

Dynamics of TLC structure during 7-day hypokinesia in antiorthostatic position (M±m)

Parameters	Stage of study				
	0	I	II	III	IV
VC	4.87±0.1	4.66±0.13	4.35±0.14**	4.38±0.11**	4.7±0.07
TLC	6.62±0.2	6.39±0.18*	5.89±0.16**	5.99±0.17**	6.25±0.14*
FRC	3.13±0.07	2.51±0.16*	2.3±0.17*	2.4±0.13*	2.41±0.16*
RV	1.8±0.11	1.7±0.11	1.54±0.11*	1.6±0.1*	1.55±0.12*
RV/TLC %	27.19±0.8	27.07±1.0	26.15±1.5	26.71±1.0	24.8±1.5
Lung CV	0.77±0.1	0.92±0.06	1.24±0.11**	0.9±0.16	0.89±0.09
CC	2.57±0.11	2.66±0.09	2.78±0.11	2.63±0.1	2.44±0.08
CV/VC %	15.81±2.0	19.74±1.0	27.5±3.0**	22.55±1.0**	18.04±2.0
CC/TLC %	38.82±2.0	41.47±1.0	47.2±1.4**	43.1±1.4	39.04±0.9
CC/FRC	0.82±0.03	1.06±0.09*	1.24±0.08***	1.1±0.04***	1.01±0.07*

*P<0.05 **P<0.02 ***P<0.01

Our findings shed light on the mechanism of hypoxemia with exposure to such factors. By the 7th hour of ANOH at -15°, FRC dropped to such an extent that it was less than CC, which had increased by this time and, accordingly, the CC/FRC ratio exceed 1. This means that the airways close in some parts of the lungs within the respiratory volume (see Figure 3). In these areas, there is impairment of alveolar ventilation and reduction of ventilation/perfusion ratio ($\dot{V}/\dot{Q}$). The decline of regional $\dot{V}/\dot{Q}$ is associated with increased admixture of venous blood to arterialized blood, and it leads to underoxygenation of arterial blood.

Figure 3.
Dynamics of changes in FRC (solid line) and CC (dash line) during -15° ANOH
The dots indicate statistically reliable difference (P<0.05) from base values

In recent years, much attention has been given to changes in CC and FRC ratio in studies of the mechanisms of hypoxemia. It has been shown that, with change from vertical to horizontal position, even healthy people show a substantial change in CC/FRC ratio [15] and increase in CV [16].

In our study, we determined CV from the start of the 4th phase of the expiratory curve; however, the origin of this phase cannot be considered definitively established as yet. In addition to the vertical gradient of pleural pressure, the elastic properties of the lungs, distribution of regional volumes and critical pressure of airway closure may influence its formation.

Kaneko [11] demonstrated on models of the lungs that a change in actually existing vertical distribution of regional volumes to the reverse, in the form of an overturned triangle was associated with considerable increase in CV. Such redistribution of lung volumes, caused by antiorthostatic position, could also contribute to increase in CV in tilted position and lead to regional

closure of airways within the limits of the respiratory volume. One must also take into consideration the effect of contraction of the diaphragm, which could have an appreciable effect on the fourth phase in horizontal position [17] and probably a more perceptible one in antiorthostatic position.

Thus, under hypokinetic conditions with an altered vector of gravity, there is substantial alteration of the TLC structure with decline of ventilation level (FRC), regional closure of small airways within the limits of the respiratory volume and, accordingly, impairment of regional ventilation-perfusion ratios. These data are indicative of the need for further refinement of methods and means of preventing the adverse effects of weightlessness on man.

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EVALUATION OF HUMAN BLOOD MORPHOLOGICAL COMPOSITION DURING EXERCISE IN SEALED CHAMBER WITH DIFFERENT CONCENTRATIONS OF AMMONIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 9 Aug 82) pp 43-45

[Article by M. P. Kalandarova, V. P. Savina and L. N. Mukhamediyeva]

[English abstract from source] Test subjects were kept in an enclosure for 17-31 days. The ammonia concentration was maintained at 5.0±0.1 and 2.1±0.1 mg/m^3 and elevated to 9.8±0.1 mg/m^3 for a short period of time. Following each exercise test on a bicycle ergometer (at 50 and 75% $\dot{V}_{O_2max}$) performed during this exposure the count of formed elements (leukocytes, neutrophils, lymphocytes, monocytes and platelets) increased as compared to the pretest level. The changes of most formed elements were within physiological variations. The exception was leukocytes, neutrophils, particularly rod neutrophils, and monocytes whose content was higher than normal at certain stages.

[Text] One of the important tasks of biomedical support of long-term spaceflights is to make a toxicological assessment of deleterious chemical trace impurities, including ammonia, which builds up in a sealed space as a result of man's vital functions and use of polymers.

A set of exercises has been recommended for cosmonauts in order to compensate for the insufficient muscular load in weightlessness, which leads to decline of hemopoiesis and changes in osseous tissue. In turn, blood changes are one of the causes of diminished endurance of physical (and orthostatic) loads.

For this reason, it was interesting to determine the degree of integrity of the bone marrow reserve of subjects during a stay in a sealed chamber, in particular, when there are low concentrations of ammonia in the atmosphere.

For this purpose, we used as a functional test a physical load which, as we know [1], helps demonstrate the functional reserves of the hematological system.

Methods

We conducted the studies in a sealed chamber 24 m^3 in size. In the first test, which lasted a total of 31 days, ammonia concentration was raised to 5.0±0.1 mg/m^3

for the period from the 8th to 24th days (there was no ammonia in the chamber for the first 7 days and the last 7 days).

In the second study, which lasted a total of 39 days, ammonia concentration was raised to 2.0±0.1 mg/m^3 from the 8th to 39th days and to 9.8±0.1 mg/m^3 for 1 day (there was no ammonia in the chamber for the first 7 days).

The other habitat parameters were as follows: ambient temperature 21.9±0.6°C, relative humidity 37±0.7%, oxygen content 21.8±0.6% and carbon dioxide content 0.37±0.1%.

There was no ammonia in the chamber during the third study (control group).

We submit here the results of analyzing blood (erythrocytes, hemoglobin, reticulocytes, thrombocytes, leukocytes and leukocyte formula) morphology before and after each physical load on 11 subjects (4 in each of the first and second studies and 3 in the third). The subjects exercised at two load levels on a bicycle ergometer constituting 75 and 50% of maximum oxygen uptake ($V_{O_2 max}$) lasting 20 and 5 min, respectively. The exercise rate was constant during the study period. There were 18 physical loads in all.

Results and Discussion

The main data on results of our studies are listed in the Table. With a physical load (75% $V_{O_2 max}$) the participants of all three studies failed to demonstrate appreciable changes in red blood cell, hemoglobin and reticulocyte counts. Thrombocyte count was in the normal range, but it was somewhat higher after exercise than before. White blood cell, neutrophil and lymphocyte counts were somewhat higher after exercising on the bicycle ergometer than before the exercise test.

Influence of graded exercise in sealed chamber on hematological parameters

Parameter	First study (50% $V_{O_2 max}$)		Second study (75% $V_{O_2 max}$)		Third study (75% $V_{O_2 max}$)	
	before	after	before	after	before	after
	exercise load					
Erythrocytes, 10^6	5.6±0.17	5.7±0.2	5.3±0.1	5.3±0.1	4.6±0.4	4.7±0.3
Hemoglobin, g%	16.1±0.8	16.9±0.7	15.3±0.6	15.3±0.5	15.6±0.6	15.8±0.7
Reticulocytes, %	7.5±0.8	9.0±1.8	8.25±0.4	6.25±0.65	4.0±0.08	8.3±1.2
Thrombocytes	–	–	182.7±11.3	343.0±14.5	318.3±21.1	357.6±32.1
Leukocytes	8.6±0.4	12.9±1.3	4.5±0.2	5.6±0.4	6.6±0.4	7.6±0.7
Neutrophils	5.5±0.56	8.1±0.9	2.4±0.4	2.8±0.4	3.3±0.16	3.7±0.5
Stab nuclears, $10^3/\mu\ell$	0.7±0.1	1.0±0.3	0.46±0.07	0.33±0.02	0.1±0.09	0.3±0.2
Lymphocytes	2.4±0.08	3.6±0.4	1.6±0.18	2.0±0.09	2.7±0.3	3.2±0.4
Monocytes	0.47±0.16	0.91±0.11	0.36±0.1	0.66±0.045	0.4±0.1	0.8±0.1
Eosinophils	0.17±0.06	0.22±0.06	0.15±0.03	0.06±0.003	0.07±0.004	0.17±0.09
Basophils	0.07±0.06	0.07±0.05	0	0.06±0.037	0.17±0.05	0.15±0.02

Stab nuclear count was often high both before and after exercise. We failed to demonstrate a clearcut dependence of eosinophil and basophil content on

level of graded exercise. In particular, during several of the tested periods, their counts were higher before pedaling on the bicycle ergometer than after, and the fluctuations did not exceed the normal range.

Monocyte level was always higher after physical exercise than before, and in some periods of the study monocyte content was somewhat above normal. We found no appreciable differences between hematocrit levels before and after exercise.

The quantity of erythrocytes, hemoglobin and reticulocytes was in the normal range both before and after exercise with use of a physical load (50% $V_{O_2}max$).

Thrombocyte and leukocyte levels were higher after exercise than before. In most periods of the study their levels did not exceed normal. However, at some stages (22d day in subjects used in the first experiment) there was leukocytosis following exercise $(8.6\pm0.4)\cdot10^3$-$(12.9\pm1.3)\cdot10^3/\mu\ell$ blood. We failed to demonstrate consistent change in dynamics of basophil and eosinophil content. At some stages of the study the number of these cells was somewhat higher after exercise than before; at other stages, the reverse was observed. Neutrophils and their stab nuclear forms presented higher levels after exercise than before, the neutrophil content remaining essentially in the normal range. Neutrophil count exceeded base values only at some stages of the study. Monocyte content was above normal, both before and, particularly, after exercise. Before pedaling on the bicycle ergometer, monocyte count essentially corresponded to normal, but exceeded the norm after exercise.

Thus, physical exercise elicited no appreciable quantitative changes in blood. In particular, we failed to detect a noticeable difference between pre-exercise and post-exercise levels of red blood cells and hemoglobin. Analogous findings have been made by other researchers [2-6]. The quantity of some formed blood elements (thrombocytes, leukocytes and most hemogram parameters) changed more noticeably than red blood parameters. However, the changes in most of them did not exceed the range of physiological fluctuations. Leukocytes, neutrophils, particularly their stab nuclear forms, and monocytes were exceptions, and their levels exceeded the norm at some stages of the study.

V. V. Matov also reported leukocytosis during exercise [7]. Blood changes during exercise are of a stress nature in the opinion of a number of authors [3, 5, 6, 7]. The study of V. Ya. Rusin et al. [8] merits attention: according to their data the quantitative blood changes during exercise are related to degree of conditioning. In particular, unconditioned subjects presented the reverse relationship between hemoglobin and red blood cell count. The levels of erythrocytes and hemoglobin can fluctuate over a rather wide range and not always in the same direction, but remain in the range of the physiological norm. When there is an increased need for neutrophils, there is release of stab and segment nuclears from the bone marrow stock of granulocytes (myogenic granulocytosis), whereas mononuclear cells, which release the colony-stimulating factor, are the humoral regulator of granulocytopoiesis [9-11].

The increase in number of most white blood cells, both granulocytes and agranulocytes, as well as thrombocytes after exercising on the bicycle ergometer, as compared to their levels before the physical load, is indicative of retention of the bone-marrow reserve in subjects spending a long time (17-31 days) in a

sealed chamber with low concentrations of ammonia in the air. This confirms the fact that a concentration of ammonia of 5.0±0.1 mg/m^3 and brief increase to 9.8±0.1 mg/m^3, against the background of prior exposure to 2.0±0.1 mg/m^3 in a sealed chamber, has no appreciable influence on functional activity of bone marrow and its physiological regeneration.

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METABOLIC DISTURBANCES IN MAN IN AN ENVIRONMENT WITH LOW AMMONIA LEVEL AND THEIR CORRECTION BY GRADED PHYSICAL EXERCISE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 1 Mar 83) pp 46-49

[Article by L. N. Mukhamediyeva, V. V. Zhuravlev, Ye. I. Nikitin, K. V. Grishina, S. M. Ivanova and S. K. Shishkina]

[English abstract from source] In two series of prolonged studies metabolic changes of men kept in an environment with an ammonia concentration of 2 and 5 mg/m^3 were investigated. In this chronic study the following changes were seen: acetone in the exhaled air increased; glycolysis and lactate dehydrogenase enhanced; catalase decreased; changes of acid-base equilibrium manifested as metabolic acidosis of varying degree. The use of exercises of different workloads showed that those at 50% $\dot{V}_{O_2max}$ were the most beneficial.

[Text] The specifics of man's life in confined quarters cause constant presence of ammonia in the air environment. The estimated MPC [maximum permissible concentration] for ammonia in the air of sealed spaces are in a low range, up to 5 mg/m^3. At the same time, it is known that 4-8-h contact with ammonia in a concentration of 2-5 mg/m^3 elicits specific changes in bioelectric activity of the brain, which are reversible, as well as depression of redox processes in the human body [1-4]. Consistent phasic changes in higher nervous activity, depression of hemopoiesis and protein metabolism have been described in seamen who had been in long-term contact with ammonia in concentrations of 0.3-3 mg/m^3 [5]. We submit here the results of a study of changes in some biochemical parameters of man under the influence of inhalation of low concentrations of ammonia.

Methods

We conducted 2 series of studies lasting 30 and 40 days, which differed in essence only in ammonia level in the atmosphere of a sealed chamber: 2.1±0.1 mg/m^3 in the first series and 5.0±0.1 mg/m^3 in the second. In both series the habitat conditions were identical: ambient temperature 20-22°C, oxygen 20-21%, carbon dioxide 0.3-0.4%. The studies were conducted with the participation of 8 essentially healthy men 27-42 years of age. They were submitted to two work loads on a bicycle ergometer, which constituted 75 and 50% of $\dot{V}_{O_2max}$,

for 5 and 20 min, respectively. Load rate did not change during the test period. In the course of the studies, in addition to measuring blood pressure, pulse and respiration rates, we studied the dynamics of redox processes in the bdoy [6, 7]: blood lactate, acetone content of exhaled air by the method of gas chromatography, gas-exchange function of the lungs on a Spirolite-2 instrument [8] and erythrocyte energy metabolism [19-23]. The data were submitted to statistical processing by the method of Student [9, 10].

Results and Discussion

With inhalation of ammonia in a concentration of 2.1 ± 0.1 mg/m^3, there was slight increase in acetone in exhaled air and statistically significant ($P<0.05$) increase with use of ammonia in a concentration of 5 mg/m^3, which was indicative of activation of the glycolytic pathway of metabolic processes.

Investigation of gas-exchange function of the respiratory system and acid-base equilibrium revealed that being in an air environment containing 5.0 ± 0.1 mg/m^3 ammonia is associated with intensification of respiratory function ($P<0.05$). There was an increase in minute volume of oxygen uptake and elimination of carbon dioxide, with signs of marked metabolic acidosis. There are data in the literature indicative of depression of tissue respiration and accumulation of ketone bodies in blood in the presence of ammonia intoxication [14-17].

According to our data, an increase ($P<0.01$) in intensity of glycolysis and activity of lactate dehydrogenase (LDH) inherent in hypoxic states was observed after the 12th day of contact with ammonia in a concentration of 2.1 ± 0.1 mg/m^3 (see Table).

During this period, no disturbances were demonstrable in the pentose-phosphate oxidation pathway. The decline ($P<0.01$) in concentration of ATP was apparently related to increased activity of transport ATPases and is intended to maintain the red blood cell structures. A distinct decline was demonstrated in blood serum catalase activity during exposure to ammonia at all tested concentrations. The intensity of decline in activity of this enzyme was related to the concentration of ammonia in the air environment and duration of exposure to it. The decline in activity of erythrocyte acetylcholinesterase (ACE) and nonspecific cholinesterase (NCE) of blood plasma was also indicative of the adverse effect of the environment (see Table).

In order to correct activity of glycolytic processes, a study was made of the adapting effect of muscular activity at different levels of intensity and of different duration, which is instrumental in increasing gas exchange and optimizing cardiovascular function [18-21]. Exposure of the subjects to an atmosphere containing ammonia in the tested concentrations had no effect on physical work capacity. It averaged 816.8 ± 33.62 kg-m/min (according to the results of the PWC_{170} test).

Figure 1 illustrates the dynamics of acetone level in exhaled air, blood lactate and oxygen uptake estimated per 100 kg-m/min exercise, before and after pedaling on a bicycle ergometer at 75% of $\dot{V}_{O_2max}$ in an atmosphere containing 2.1 ± 0.1 mg/m^3 ammonia. With increase in duration of contact with ammonia there

was decrease in concentration of acetone in exhaled air. From the 16th day on no significant difference was demonstrable between its pre- and post-exercise levels. We could have interpreted this pattern of acetone levels in exhaled air as a manifestation of conditioning. However, the simultaneous elevation of blood lactate level, some decline in oxygen uptake and rise of respiratory quotient to 0.998 were indicative of increase in share of anaerobic pathway of energy formation.

Dynamics of energy metabolism and ACE activity in erythrocytes, as well as catalase and NCE activity in subjects' blood plasma (M±m)

Parameter	Base data	Day of exposure to ammonia			Recovery period
		6	12	24	
ATP, μmM/g Hb	6.011±0.129	6.359±0.129	7.277±0.349	4.918±0.109	7.627±1.528
P	—	—	<0.05	<0.01	>0.1
Intensity of glycolysis (according to lactic acid increment), μm M/g Hb	8.800±0.434	8.357±1.089	10.052±0.979	18.068±0.398	8.689±1.031
P	—	—	—	<0.001	>0.1
ADH activity, μmM $NADH_2$/g Hb	15.30±1.252	20.428±0.581	32.829±1.264	29.83±2.449	29.032±1.094
P	—	<0.05	<0.001	<0.01	<0.1
G-6-PD activity, μmM $NADPH_2$/g Hb	3.935±0.391	3.962±0.220	4.769±0.110	4.526±0.559	5.012±0.381
P	—	—	—	—	—
Catalase (index)	3.17±0.114		2.98±0.077	2.77±0.086	2.88±0.243
P	—		>0.2	<0.02	>0.2
ACE, μmM ATKh* mℓ/h	1058.3±41.93	50.79	1109.2±50.79	805.2±38.13	927.83±39.90
P	—		<0.02	<0.01	>0.1
NCE, μmM ATKh mℓ/h	159.5±6.01		149.15±7.82	157.3±16.74	167.02±11.02
P	—		<0.05	—	>0.1

*Expansion unknown

A comparison of biochemical and physiological data obtained during the period of exercise at the rate of 50% of $\dot{V}_{O_2max}$ (Figure 2) revealed that, during such exercise, compensatory homeostatic reactions adequate to the work load develop in the human body. This is indicated by the decline of acetone level in exhaled air and blood lactate, decreased increment of systolic pressure and pulse rate with increase in time the subjects spend in an atmosphere containing ammonia in the tested concentration.

From the first day of the subjects' exposure to an atmosphere containing 5.0±0.1 mg/m^3 ammonia the acetone content of exhaled air rose to 5.4 mg/m^3. Thereafter, we failed to demonstrate a significant difference between its levels before and after working on the bicycle ergometer. At the same time, the nature of increment of blood lactate was similar to the preceding group, but more marked. Starting on the 15th day, we observed a reliable ($P<0.05$)

increase in blood lactate after exercising at the rate of 75% $\dot{V}_{O_2max}$. When exercising at the rate of 50% of $\dot{V}_{O_2max}$, lactate increase by the 15th day of exposure to ammonia constituted only 1.6 mg%.

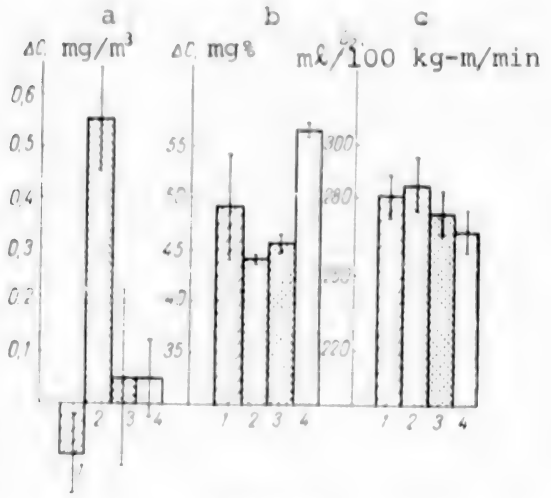

Figure 1.
Dynamics of increase in acetone in exhaled air (a), blood lactate (b) and oxygen uptake (c) during exercise at rate of 75% of $\dot{V}_{O_2max}$
1) base level
2, 3, 4) parameters on 2d, 16th and 34th days of exposure to ammonia

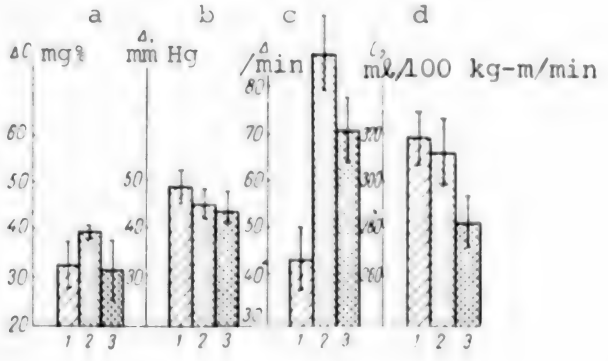

Figure 2.
Dynamics of increase in biochemical and physiological parameters and oxygen uptake during exercise at 50% of $\dot{V}_{O_2max}$
a) lactate
b) systolic BP
c) pulse rate
d) oxygen uptake
1) base level
2,3) 9th and 24th days of exposure to ammonia

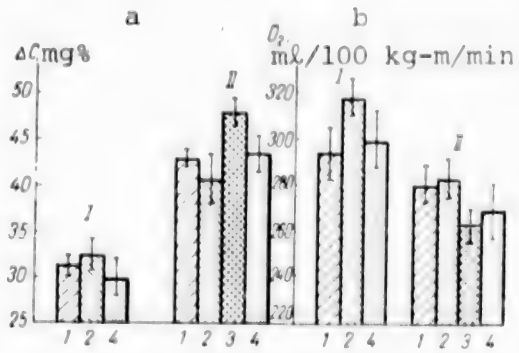

Figure 3.
Dynamics of blood lactate increment (a) and oxygen uptake (b) during exercise at 50% (I) and 75% (II) of $\dot{V}_{O_2max}$
1) base level
2,3,4) on 6th, 15th and 18th day of exposure to ammonia

A comparison of intensity of lactate increment and oxygen uptake during exercise by the subjects at the rates of 50 and 75% of $\dot{V}_{O_2max}$ revealed that working at 50% of $\dot{V}_{O_2max}$ is rational, in the sense of eliciting minimal changes in man (Figure 3).

To sum up the obtained data, it can be concluded that prolonged (up to 35 days) and continuous inhalation of ammonia in concentrations of 2 and 5 mg/m^3 has an inhibitory effect on redox processes in the human body. It is expedient to use the adapting effect of muscular activity to activate these processes during exposure to the gas environment inherent in sealed spaces with ammonia content of 2 and 5 mg/m^3. Physical exercise at the rate of 50% of $\dot{V}_{O_2max}$ is the optimum in individual dosing out of a load on muscles, and it has a conditioning effect on man. In assessing our findings, one should also take into consideration the fact that the set of factors

that are inherent in living conditions in small, sealed spaces has an effect on biochemical processes in the body.

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METABOLISM AND NUTRITIONAL STATUS IN EMERGENCY SITUATIONS WITHOUT FOOD SUPPLY OR ON A LOW-CALORIE DIET

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[Article by I. G. Popov, P. A. Lozinskiy, A. A. Latskevich and I. A. Romanova]

[English abstract from source] The comparative study of the metabolism and nutritional status of test subjects who 3-5 days were in a contingency situation with no or low-calorie (300 g chocolate) food available demonstrated the advantage of even this inadequate diet as compared to no food.

[Text] In view of the relative small weight and size of portable emergency kits (PEK) used in aviation that include a supply of food, in case of forced landing on the ground or in water, in an uninhabited place, flight personnel usually have low-calorie (subcalorie) food available [1, 2].

In developing low-calorie survival rations, one of the most important questions is their energy value and amounts of vitally needed essential nutrients they contain. These questions have been a concern for a long time, but they have not yet been adequately worked on. There are different views about the minimum permissible nutritional value of emergency rations, and sometimes they are quite contradictory. Some authors [3] concluded, on the basis of clinical and physiological studies of "emergency situations" lasting 3 days, that a reduction of energy value of rations to less than 1150-2080 kcal/day is associated with a state that is virtually no different from total starvation. It has also been reported that, in order to survive in an uninhabited area, it is necessary to issue daily rations amounting to at least 2000 kcal, including 15% protein, 52% carbohydrates and 33% fat [4]. At the same time, another group of researchers [5, 6] believe that even partial replenishment of nutrient resources of the body in emergency situations is better than a total fast.

We report here the results of a study of the dynamics of nutritional status and metabolism of subjects who received no food for 3-5 days in a simulated emergency situation for pilots. We have compared these data to the results of our prior studies.

Methods

We simulated one of the variants of development of an emergency situation in our physiological and hygienic studies of metabolism and nutritional status of subjects who received no food for 5 days, as well as with use of low-calorie "survival" rations containing 300 g chocolate. The subjects received the standard preflight breakfast on the day the studies began (at 0900 hours); it consisted of about 1017 kcal--43 g protein, 46 g fat and 115 g carbohydrates. The net weight of the breakfast was about 505 g. They were given 200 mℓ hot tea and 200 mℓ fruit juice at breakfast time. "Take off" was announced 1.5 h after breakfast and an "emergency landing" after another 2 h. From this time on, the subjects either received no food at all for 5 days or used the standard low-calorie emergency rations consisting of 300 g chocolate. Mealtime schedule with use of emergency rations called for intake of 20 g chocolate on the evening of the 1st day, then 70 g chocolate on the 2d to 5th days, which was taken in approximately three even parts at the usual breakfast, lunch and supper times [7]. The fluid intake norm was set at about 1 ℓ/day. In addition, the subjects were given about 400 mℓ water on the 1st day, with their preflight breakfast. Each day was considered to start at 0800 h after collecting the preceding night's urine, so that the 1st day included the preflight breakfast issued at 0900 h. Consequently, 0800 hours of the 6th day was considered as the end of the 5th day of the study.

Men 35-40 years of age participated in these studies; they had undergone a medical examination and were deemed to be essentially in good health. There were some subjects who were overweight, some of normal weight and some who were underweight, as would be found under ordinary living conditions. We studied the dynamics of metabolism and nutritional status on a daily basis on according to measurement of body weight, parameters of carbohydrate, nitrogen, amino acid, mineral and lipid metabolism. We took into consideration the dynamics of parameters of subjective and objective physical condition of the subjects, their work capacity, appetite, sensation of hunger and thirst. In simulating emergency conditions with respect to food, the subjects continued to perform their customary work which involved average energy expenditure of 3000-3200 kcal/day, with some physical exercise under conditions of temperate climate and rather comfortable temperature.

Results and Discussion

Table 1 lists the results of dynamic measurement of the subjects' weight when on a total fast under emergency conditions for 3 and 5 days after the preflight breakfast. It lists data referable to two groups of subjects: the first consisted of those who spent 5 days in the emergency situation and the second, 3 days. Table 1 shows that, under the above-described conditions, all of the subjects continuously lost weight during the emergency period. Maximum weight loss was observed on the 1st and 2d days. In both groups, mean weight loss over the first 3 days was about the same. By the end of the 3d day, all of the subjects lost an average of 3.65±0.13 kg. This constitutes 4.62±0.13% of initial weight. In a number of cases, men who had a higher base weight showed less percentile decline of this parameter than those with a lower base weight. On the next 4th and 5th days, weight loss diminished somewhat in most subjects. By the end of the 5th day, total weight loss averaged 5.44±0.15 kg, or 6.68±0.26%.

Initially, among the subjects there were individuals who were overweight, some with normal weight and some who were underweight, according to Broca's index. The overweight subjects continued to be overweight after a 3-day fast. After a 5-day fast, only 2 men were still overweight. The subjects with low and normal weight presented distinct signs of malnutrition after 5 days. According to Broca's index, the weight loss constituted 3.75-4.80 kg. After 5 days, 1 subject who was underweight at the start had a weight deficiency of 5.2 kg according to Broca's index. Thus, judging by Broca's index, the individuals who had a normal weight, let alone those who were underweight initially, were in a substantially poorer situation, while the weight loss in 3 and 5 days was relatively the same (according to absolute levels and percentage).

In general, the weight loss, which constituted 4.62±0.13% in 3 days and 6.68±0.26% in 5 days, should be assessed as moderate and far from being dangerous to health (the critical level is loss of 30-50% of initial weight) [8]. When using the emergency rations consisting of 300 g chocolate under similar conditions, it was demonstrated that weight loss was 3.28±0.17 kg in 3 days (4.17±0.14%) and 4.29±0.11 kg (5.46±0.09%) in 5 days [7].

Consequently, even with use of the very low-calorie rations, there was less weight loss than on a complete fast. In the latter case, weight loss was an average of 0.37 kg more in 3 days and 1.15 kg more in 5 days than with use of the low-calory rations of 300 g chocolate [7]. The difference between weight loss in both emergency situations was unreliable for the first 3 days ($P>0.05$) and reliable over the 5 days ($P<0.05$). Weight loss (percentile) was 0.45% greater in 3 days than with use of low-calorie rations (300 g chocolate) ($P<0.001$) and 1.22% greater in 5 days ($P<0.001$). Consequently, if the emergency conditions are extended from 3 to 5 days without food, the difference in nutritional status increases appreciably in a direction that is adverse for the body, as compared to use of low-calorie rations.

According to medical monitoring data and subjective evaluation of the men themselves, which they logged daily, their general condition and work capacity were typical of the early stage of total fasting. On the 1st day, hunger appeared already by 1300-1400 hours, i.e., at the time of the next meal. In accordance with the developed recommendations, upon appearance of hunger the subjects took 70-100 ml cold water (2-3 sips). It was found that warm water satisfied hunger less well. By the end of the 1st day, the next exacerbation of hunger was associated with weakness and irritability. On the 2d and 3d days, hunger, general weakness and unwillingness to work increased, but the subjects continued to perform their routine professional duties, which were characterized in most cases by mental work. The feeling of weakness was manifested the most when walking, climbing steps, i.e., when performing physical work. As before, all of the subjects reported exacerbation of hunger at the usual times for breakfast, lunch and supper, which became somewhat duller after taking 2-3 sips of cold water. By the 3d day, some subjects had a mouth odor of sour apples, periodically were somewhat nauseous, particularly at night.

Virtually all of the subjects reported at this period that the sensation of hunger and general weakness troubled them the most when they were not working, i.e., when they concentrated their attention on "their own sensations."

Table 1. Dynamics of weight with subjects on total fast for 3 and 5 days in emergency situation

Subject	Initial weight, kg	Height, cm	Initial deficit of body weight, kg	Weight reduction, kg/day (% of base weight given in parentheses)							Weight after 5-day fast, kg	Residual weight (A.A. Petrov-Maksimov), kg	Weight gain after 5-day fast, kg
				Day									
				1	2	3	1–3	4	5	1–5			
First group													
L-ii	88.00	184	+4.00	1.85 (2.10)	0.65 (2.84)	1.00 (3.98)	3.50 (3.98)	0.95 (5.06)	0.75 (5.91)	5.20 (5.91)	82.8 (84.5)*	79.2	1.1 (−0.56)*
G-ov	85.65	178	+6.65	1.10 (1.39)	1.40 (3.03)	1.05 (4.25)	3.50 (4.26)	1.25 (5.72)	1.05 (6.95)	5.80 (6.95)	79.85 (82.15)*	73.8	1.85 (−4.15)*
L-ich	79.20	172	+7.20	1.60 (2.04)	1.25 (3.62)	0.95 (4.80)	3.80 (4.80)	0.65 (5.62)	0.95 (6.82)	5.40 (6.82)	73.80 (75.40)*	69.7	1.80 (−3.40)*
V-ets	76.30	178	−1.70	1.60 (2.10)	0.90 (3.28)	1.00 (4.59)	3.50 (4.59)	0.80 (5.64)	1.05 (7.02)	5.35 (7.02)	70.95 (72.80)*	67.3	−7.05 (−5.20)*
Average			—	1.56± 0.16	1.05± 0.18	1.00± 0.02	3.68± 0.07	0.91± 0.15	0.95± 0.07	5.44± 0.15	—	—	—
Second group													
P-ov	85.85	177	+8.85	1.65 (1.92)	1.60 (3.78)	1.10 (5.06)	4.35 (5.06)	—	—	—	—	—	—
S-ov	80.50	181	−0.50	1.70 (2.11)	1.30 (3.72)	1.10 (5.09)	4.10 (5.09)	—	—	—	— (81.50)*	79.8	— (−4.50)*
K-ov	76.55	172	+4.55	1.45 (1.89)	0.80 (2.93)	0.90 (4.11)	3.15 (4.11)	—	—	—	— (76.40)*	78.8	— (−4.60)*
P-in	75.70	176	−0.3	1.15 (1.52)	1.10 (2.97)	1.20 (4.55)	3.45 (4.55)	—	—	—	— (73.40)*	69.7	— (−1.40)*
K-ov	67.70	168	−0.3	1.70 (1.92)	1.10 (3.54)	1.10 (5.16)	3.50 (5.16)	—	—	—	— (72.25)*	72.5	— (−3.75)*
											— (64.20)*	59.3	— (3.80)*
Average for 2d group				1.45± 0.12	1.18± 0.17	1.08± 0.07	3.71± 0.26	—	—	—	—	—	—
Average for 1st and 2d groups				1.50± 0.08	1.12± 0.11	1.04± 0.03	3.65± 0.13	—	—	—	—	—	—

*Data on status on 3d day in emergency situation without food are given in parentheses.

Table 2. Dynamics of glucose level (mg%) in subjects' blood on complete fast for 3 and 5 days

Subject	Broca's index	Day of total fast										Day of rehabilitation diet				
		1*	2		3		4		5		6**	1	2		3***	
First group																
L-iy	+1.00	80	74	70	54	50	45	46	43	52	47	43	69	60	65	63	74
M-ov	+7.65	69	65	60	56	53	42	50	44	49	49	48	63	53	66	62	70
L-ich	+7.20	83	67	75	53	55	60	55	48	60	58	50	64	71	64	65	69
V-ets	−1.70	76	67	65	48	57	49	51	48	54	47	59	61	62	67	64	72
Average for 1st group		77.0 ±3.40	68.3 ±2.18	67.5 ±3.64	52.8 ±1.91	53.8 ±1.70	49.0 ±1.37	50.5 ±2.67	45.8 ±0.97	53.8 ±1.91	50.3 ±2.67	50.0 ±3.89	64.3 ±1.91	61.5 ±4.37	65.5 ±0.73	63.5 ±0.73	71.3 ±1.21
Second group																
P-ov	+8.85	76	71	72	56	58	53	54	—	—	—	—	59	62	70	60	71
S-ov	−0.50	80	76	60	53	54	41	44	—	—	—	—	58	64	68	61	65
K-ov	+4.55	68	69	61	50	41	49	46	—	—	—	—	56	60	62	96	65
P-in	−0.3	69	71	70	54	48	42	51	—	—	—	—	62	63	81	81	74
K-ev	−0.3	81	78	61	51	49	42	46	—	—	—	—	64	60	68	74	78
Average for 1st and 2d gr.		75.8 ±1.35	70.9 ±1.46	66.0 ±1.69	52.8 ±0.90	51.7 ±1.9	47.0 ±2.13	49.2 ±1.21	—	—	—	—	59.6 ±1.71	61.8 ±2.87	69.8 ±1.11	74.4 ±7.62	70.6 ±2.83

Note: Blood was taken at 0900 and 1800 hours.

*Fasting, before preflight breakfast.
**At 0900 hours on 6th day of study.
***At 0200 hours on 3d day of rehabilitation diet.

Individuals who were on a total fast for 3 days reported that their condition enabled them to perform their professional duties, although this did require some will power. Those who were on a total fast for 5 days reported that hunger bothered them less on the 4th and 5th days than on the 2d and 3d, and if necessary they could have remained on the fast for a longer time and still do their job.

The subjects reported unanimously that their subjective condition was better with use of the low-calorie (300 g chocolate) rations in an emergency situation than with total abstinence from food.

Dynamometric testing of strength of hands and "stance strength" on the fast revealed that, while there was both some increase and decrease of these parameters on the first 3 days, most subjects demonstrated a decline of strength on the 4th and 5th days. With use of the low-calorie rations, the results of dynamometry were better, particularly on the 4th and 5th days.

Examination of cardiac function by means of electrocardiograms (EKG) failed to reveal any particular pathological changes.

Table 2 lists the results of assaying blood glucose levels. Blood was taken from a finger twice a day, at 0900 and 1800 hours. We used the glucose oxidase method in the modification of I. S. Balakhovskiy, in which the physiological norm was 7.0-10.7 mM, which is rather close to the norm for the usual clinical modification of the glucose oxidase method, 56-94 mg% [10]. On the 1st day of the emergency situation, when the subjects took no food at all after the preflight breakfast, glucose concentration in blood remained in the normal range, but there was a tendency toward decline in most cases. On the 2d day, blood glucose concentration was also in the normal range in all subjects, but with a tendency toward further decline in most cases. Starting on the evening of the 3d day and to the end of the 5th day all subjects presented signs of hypoglycemia. With the change to the rehabilitation diet after 3- and 5-day fast blood glucose level rapidly returned to normal. If we compare the blood glucose concentration during the fast to the level demonstrated with use of low-calorie rations under analogous conditions (300 g chocolate) [7], we shall see that in the case of total fast there was prevalence of hypoglycemia starting on the evening of the 2d day, whereas on the low-calorie rations there was sporadic hypoglycemia. The latter was more marked on the 4th and 5th days and in the second half of the 2d and 3d days. Thus, even the low-calorie rations with low nutrient value (300 g chocolate) has a beneficial effect on blood glucose and creates a better status according to this parameter than a total fast.

On a fast, as well as low-calorie diet, there is depressed utilization of acetyl-CoA in the Krebs cycle and synthesis of fatty acids, since all available reserves of the body are converted into blood glucose. As a result, there is increased synthesis of ketone bodies and development of ketonemia, which is usually associated with ketonuria. Examination of ketone body excretion in urine using the modified method of Imber and Bonsamur [2] revealed the following. In the initial period on the usual diet and on the 1st day of the emergency situation, when a preflight breakfast was taken, ketone bodies were virtually absent from urine. Ketone bodies were demonstrated in all subjects, in amounts of 0.25 to 0.56 g/day in 24-h urine samples for the 2d day of the emergency situation, when the subjects consumed no food at all, i.e., on a complete fast.

Ketone bodies were present in 24-h urine in amounts of 0.98 to 2.30 g/day on the 3d day, 2.94 to 3.28 g/day on the 4th day and 3.57 to 4.25 g/day on the 5th. Consequently, ketonuria increased appreciably in all subjects with increase in duration of "emergency situation" without food. Apparently, there was a sufficient supply of glucose, glycogen and carbohydrates from the preflight breakfast to prevent ketonemia and ketonuria only on the 1st day. If we compare the above data to the results obtained with use of low-calorie rations (300 g chocolate) [7], we shall see that more marked ketonuria is observed on the total fast, i.e., starting on the 2d day of the emergency situation. Under these conditions, the increase in ketonuria was particularly noticeable on the 4th and 5th days.

As we know, protein metabolism is among the first to experience considerable stress on a total fast. At the early stages of fasting, amino acids are actively involved in gluconeogenetic processes, in addition to participation in plastic (anabolic) processes. Free amino acid concentration in blood plasma is an important indicator of the state of protein metabolism, sufficiency of amino acids, as well as size and dynamics of amino acid pool. Table 3 lists the results of assaying 17 free amino acids in blood plasma of subjects before and after 3-day (2d group of subjects) and 5-day (1st group) exposure to "emergency situation" without a supply of food. Amino acids of plasma were assayed on a fasting stomach, at 0800 hours, using an automatic analyzer [11].

In the base state on the usual diet, the concentrations of most amino acids in plasma were in the normal range for adults, as listed by I. S. Balakhovskiy in the 3d edition of the Great Soviet Encyclopedia [12]. Cystine and aspartic acids were an exception, and their concentration was below the listed norms. In addition, some subjects also showed a lower than normal methionine content, whereas lysine concentration in plasma exceeded the top of the normal range. Previously, we discussed in detail the dietetic and other causes of this phenomenon [11]. Free amino acid content of plasma in the 1st and 2d groups of subjects was generally on a rather similar level in the base period, which is indicative of satisfactory food and amino acid supply.

At the end of the 3d day of the emergency situation on a total fast, the plasma levels of most essential amino acids rose in the 2d group, while the concentration of lysine and phenylalanine decreased. The concentration of most nonessential amino acids decreased, but the cystine level rose somewhat. The sum of essential amino acids increased ($P<0.01$) and that of nonessential ones decreased ($P<0.05$), and this lead to increase in ratio of essential to nonessential amino acids (E/N). The concentrations of most amino acids remained in the normal range [12], with the exception of valine, leucine, isoleucine, the levels of which in plasma exceeded the top of the normal range, as well as alanine and aspartic acids, the levels of which were below the bottom of this range.

The demonstrated changes in amino acid concentrations could be due to the process of active utilization for gluconeogenesis, under fasting conditions, of most glucoplastic (glucogenic) amino acids [13] from the pool of free amino acids of plasma, which caused their concentration to decrease. The increase in some glucoplastic amino acids was apparently due to their mobilization from the periphery and incomplete depletion of their readily accessible reserves at

this stage of fasting. The change in concentrations of ketoplastic amino acids [13] was related to activation of processes of formation of ketone body, which is confirmed by ketonuria. Under such conditions, glucoketoplastic amino acids were also utilized for analogous purposes [13]: isoleucine, phenylalanine and tyrosine, and this affected the dynamics of their concentrations in blood plasma.

Table 3. Free amino acid levels (mg%) in subjects' blood plasma on a total fast for 5 days (n = 4) and 3 days (n = 6)

Amino acid	5-day fast (1st group)		3-day fast (2d group)	
	Fasting at 0800 hours			
	1st day	end of 5th day	1st day	end of 3d day
Essential amino acids				
Lysine	3.93±0.19	2,82±0.16*	4.08±0.17	3.12±0.21*
Threonine	1.80±14	2.68±0.09**	1,79±0.12	2.23±0,09*
Valine	2.05±0.12	2.54±0.06*	1.99±0.14	3.75±0.17***
Methionine	0.28±0.06	0.23±0,08*	0.26±0.03	0.34±0.01
Isoleucine	0.73±0.09	1.22±0.11*	0.71±0.05	1.62±0.14***
Leucine	1.40±0.13	2,30±0,10**	1.47±0.10	3.30±0.33**
Phenylalanine	0.75±0.07	0.53±0.05	0.77±0.09	0.61±0.07
Nonessential amino acids				
Histidine	1.67±0.07	0.79±0.10**	1.47±0.09	1.25±0,13
Arginine	1.05±0.04	0.62±0.07*	1.26±0.08	1.20±0.04
Aspartic acid	0.13±0.04	0,05±0.01	0,12±0.00	0,05±0,02**
Serine	1.59±0.17	1,03±0.08	1.43±0,14	1,18±0,10
Glutamic acid	1.31±0.14	0,40±0.03***	1.24±0.22	0,54±0,11*
Proline	2.20±0.11	1.47±0.08**	2.08±0.14	2.02±0.09
Glycine	1.43±0.04	1.00±0.06**	1,39±0,12	1.12±0,11
Alanine	2.71±0.01	1.97±0.12**	2.26±0,20	1.91±0.17
Cystine	0.78±0.02	1.07±0.03***	0.87±0.14	1,09±0,12
Tyrosine	0.83±0.07	0,63±0,09	0,80±0,09	0.69±0,05
Sum of essential amino acids (E)	10.94±0.32	12.32±0,26*	11,07±0.29	14,97±0,46***
Sum of nonessential amino acids (N)	13.70±0.29	9,03±0,23***	12.92±0,41	11 05±0.32*
E/N ratio	0.79±0,03	1,36±0,06***	0,85±0,04	1,35±0,08***

*P<0.05 **P<0.02 ***P<0.01

At the end of the 5th day of total fast, the concentrations of the same essential amino acids--threonine, valine, isoleucine and leucine--were higher than in the base period in subjects of the first group, while the levels of the three others, lysine, methionine (in some subjects) and phenylalanine dropped. The concentrations of all nonessential amino acids, with the exception of cystine, decreased. The sum of essential amino acids increased (P<0.05) and nonessential ones decreased (P<0.01), which caused increase in the E/N ratio (P<0.01). The concentrations of most amino acids remained in the normal range [12], with the exception of isoleucine, the level of which exceeded the

top of the normal range, as well as alanine, aspartic and glutamic acids, arginine, histidine, methionine, the concentrations of which decreased to below the bottom of this range.

Analysis of the "amino acid status" of blood plasma in the second group of subjects at the end of the 5th day of the fast leads us to the following conclusion. The decline demonstrable by the end of the 3d day in concentration of most amino acids continued to the end of the 5th day. The concentrations of 3 amino acids remained on the same level as at the end of the 3d day, while 1 (threonine) even increased by the end of the 5th day. All this was due to the continuing active process of gluconeogenesis and anabolic processes on the cellular level, which utilized amino acids from plasma. After a 5-day fast, ketogenic amino acids demonstrated changes analogous to those found after 3 days, but the concentrations of leucine and lysine decreased in absolute values. Evidently, there was a decrease in stock of these amino acids. The changes in glucoketoplastic amino acids were analogous after 3 and 5 days, but the concentrations of these amino acids (isoleucine, phenylalanine and tyrosine) decreased.

Thus, although the levels of most amino acids remained in the normal range [12] by the end of the 5th day, there was an appreciable decrease in their concentration, as compared to the initial period and status at the end of the 3d day.

A comparison of concentrations of free amino acids in blood plasma of the subjects after 5 days in the "emergency situation" without food supply and in the case of using a low-calorie ration (300 g chocolate) [7] failed to demonstrate more noticeable changes in blood plasma amino acid levels in subjects who fasted. The demonstrated changes on the fast were unfavorable, due to the more significant utilization of initial amino acid resources of the body. The concentrations of most glucoplastic amino acids was lower and that of ketoplastic amino acids higher on the fast, which reflected more intensive development of gluconeogenesis and ketogenesis in the 5 days of fasting. Interestingly, in both types of "emergency situation," the dynamics of amino acid levels presented generally the same direction, but the changes were more marked with fasting.

The results of assaying total nitrogen excretion in 24-h urine in our subjects, when on a usual diet, in emergency situation without a food supply and with rehabilitation diet, as well as data on overall loss of nitrogen, are listed in Table 4. Nitrogen excretion in urine was quite similar in both groups of subjects in the base period, which was indicative of rather high supply of food proteins in their usual diet. On the first day of the "emergency situation," when the subjects only took a preflight breakfast, nitrogen excretion was lower in most cases than on the preceding day, when they were on a usual diet. Nitrogen excretion continued to decline on the 2d day of complete fast in most subjects, which is also confirmed by the mean values, although some subjects presented even an increase in nitrogen excretion. Nitrogen excretion continued to decline insignificantly on the 3d day in the 1st group of subjects. In most subjects of the 2d group, this parameter rose somewhat and exceeded the mean excretion levels for the 1st and 2d days, but remaining lower than in the base period. On the whole, according to mean values, nitrogen excretion was lower on the 3d day than in the base period with the usual nutrition, which was indicative of decrease in quantitative aspect of nitrogen metabolism. Nitrogen

metabolism had a negative balance on all 3 days, and by the end of the 3d day it reached an average of 31.79±0.26 g for the 2d group of subjects and 33.35±0.50 g for the 1st. This constitutes about 3.2 and 3.3%, respectively, of the overall nitrogen supply of the body (about 1000 g). In the 4th day of the fast, nitrogen excretion was higher in all cases than on the 2d and 3d days, apparently due to activation of gluconeogenesis at the expense of utilizing amino acids. However, on the 5th day, nitrogen excretion decreased again, and to the lowest level of all 5 days. Probably, during this period fats began to be utilized in increasing amounts for energy purposes, while gluconeogenesis at the expense of amino acids diminished somewhat due to the decline of the pool of free amino acids. This interpretation is confirmed by the increased ketonuria and decreased concentrations of most blood plasma amino acids by the end of the 5th day of the fast.

The negative nitrogen balance over the 5 days of "emergency situation" reached 58.78±0.64 g in the case of complete fast, which constitutes about 5.9% of the initial endogenous supply of nitrogen. Consequently, in the case of a 5-day fast, let alone 3-day fasting, there was considerably less loss of endogenous nitrogen than the critical level of 50%, which occurs when there is breakdown of 40-45% of the protein contained in the body [8]. For this reason, only the early stage of protein deficiency was present during the 5 days. The data referable to nitrogen and amino acid metabolism, as well as results of testing urea excretion in urine, are indicative of the fact that a protein deficiency was present. While urea excretion constituted an average of 27.14±1.43 g/day when on a usual diet, it was 14.99±0.45 g/day on the 3d day of the fast and 10.78±0.13 g/day on the 5th.

With use of low-calorie rations (300 g chocolate), nitrogen excretion in urine constituted 35.40±0.42 g in 3 days. In 5 days, nitrogen excretion was 56.16±0.75 g, which is less by about 2.8 g than on a fast [7]. The negative nitrogen balance in 5 days reached 5.2% of endogenous nitrogen supply with use of low-calorie rations, which is somewhat less than on a complete fast. With use of low-calorie rations, urea excretion in urine was higher on the 5th day and constituted 12.171±0.50 g [7]. The share of urea nitrogen in total nitrogen of urine constituted 48.80±0.97% on the 5th day of fasting and 55.00±1.63 g on the low-calorie rations. Thus, with use of the above-mentioned low-calorie rations, nitrogen metabolism was still in a better condition than on a total fast. It should be noted that nitrogen metabolism recovered already on the 3d day after the fast.

Examination of daily excretion in urine of macroelements--potassium, sodium, phosphorus and chlorine--revealed gradual decline in general. On a usual diet, daily excretion of sodium constituted 3257±118 mg and chlorine excretion 9601±332 mg. On the 1st day of the emergency situation, sodium excretion decreased insignificantly, to 3142±142 mg and chlorine to 7485±227 mg. On the 2d day, sodium and chlorine excretion in urine constituted 1240±40 and 3312±138 mg, respectively; the figures were 744±36 and 2448±131 mg on the 3d day, 494±245 and 1572±158 mg on the 4th, 464±27 and 1280±128 mg on the 5th day. The parameters of sodium and chlorine excretion on the 4th and 5th days changed little, whereas in their values they differed little and were minimal, as compared to prior days, apparently due to more intensive retention in the kidneys because of the danger of desalination of the body.

Table 4. Total nitrogen excretion (g) in 24-h urine before, during and after 3-5-day fast

Group of subjects	Day on usual diet		Day of total fast				
	1	2	1	2	3	1–3	4
first group							
L-iy	15.56	11.48	10.62	12.90	12.21	35.73	13.05
B-ov	12.90	17.12	12.62	12.35	12.24	37.21	13.10
L-ich	14.40	11.29	13.00	11.69	10.80	35.49	12.11
V-ets	16.24	18.97	13.17	12.17	10.93	36.27	11.92
Average for 1st group	14.78±0.81	14.72±1.81	12.35±0.62	12.28±0.29	11.55±0.35	36.18±0.42	12.55±0.29
second group							
P-ov	15.54	13.30	11.71	10.47	12.95	35.13	—
S-ov	13.49	14.76	12.12	10.50	12.00	34.62	—
K-ov	17.21	15.03	10.78	11.02	12.64	34.44	—
I-in	14.59	17.60	10.70	12.02	11.65	34.37	—
K-ev	15.79	11.52	12.44	10.46	12.82	35.72	—
Average for 2d group	15.32±0.81	14.44±1.32	11.55±0.38	10.89±0.35	12.41±0.28	34.86±0.29	—
Average for 1st and 2d groups	15.08±0.48	14.56±0.66	11.91±0.29	11.51±0.27	12.03±0.21	35.44±0.32	—

Group of subjects	Day of total fast		Day of rehab diet after fast		Usual	Negative N balance (N loss in urine and extrarenally)		
	5	1–5	1	2	3	1–3	4–5	1–5
first group								
L-iy	10.17	58.95	8.50	12.46	14.78	33.17	26.01	59.18
B-ov	9.88	60.19	8.55	12.77	13.45	34.57	25.71	60.28
L-ich	10.51	58.11	11.28	13.14	12.91	23.51	25.15	57.66
V-ets	10.51	58.70	12.61	13.97	13.02	33.14	24.86	58.00
Average for 1st group	10.27±0.15	58.99±0.50	10.24±0.99	13.09±0.37	13.54±0.45	33.35±0.50	25.43±0.28	58.78±0.64
second group								
P-ov	—	—	9.89	12.57	14.40	32.48	—	—
S-ov	—	—	12.48	13.50	14.00	31.50	—	—
K-ov	—	—	10.38	11.00	14.20	31.14	—	—
I-in	—	—	10.35	13.71	13.51	31.27	—	—
K-ev	—	—	12.67	12.34	12.50	32.17	—	—
Average for 2d group			11.15±0.61	13.22±0.36	13.72±0.37	31.79±0.26		
Average for 1st and 2d groups						32.48±0.37		

Potassium excretion in urine also diminished, with the exception of the 4th day, when this parameter rose to the 2d-day level. Potassium excretion in urine constituted 2333±101 mg/day on a usual diet, 1671±113 mg on the 1st day of the fast, 1231±21 mg on the 2d day, 1064±55 mg on the 3d, 1373±119 mg on the 4th and 1015±87 mg on the 5th. Potassium excretion was below the physiological norm, which is 2-3.3 g/day, already on the 1st day.

Phosphorus excretion in urine was 1232±157 mg when on a regular diet, it dropped to 822±51 mg on the 1st day of fasting, 701±39 mg on the 2d day; it rose to 936±43 mg on the 3d day, 1245±49 mg on the 4th and dropped again to 936±137 mg on the 5th day. Thus, phosphorus excretion remained in the physiological range.

These data are indicative of gradual development of potassium, sodium and chlorine deficiency as a result of uncompensated loss of these macroelements while fasting. However, in 5 days the situation did not reach a critical state, according to the subjects' general condition, dynamics of EKG and dynamometry parameters.

With use of low-calorie rations (300 g chocolate) under analogous conditions, there was generally an analogous direction of changes in sodium excretion: amounts close to those demonstrated on the fast were excreted on the 4th and 5th days. Chlorine excretion was greater on all 5 days of the "emergency situation" when the subjects fasted, particularly on the 4th and 5th days. Thus, while excretion constituted 970±109 and 863±159 mg chlorine on the 4th and 5th days of low-calorie rations, the figures were 1572±158 and 1280±128 mg on the fast. Potassium excretion was somewhat greater for the first 3 days on low-calorie rations than on a fast. However, on the 4th and 5th days (particularly the 4th), potassium excretion was, on the contrary, greater on the fast than low-calorie rations. This could be attributable to development of stress in this period and more intensive breakdown of cellular structures when fasting, since potassium is a "cellular" macroelement, unlike extracellular sodium. Phosphorus excretion diminished continuously for all 5 days on the low-calorie rations, whereas on a fast this parameter decreased on the first 2 days; it rose on the 3d day and particularly the 4th, and became higher than on the 1st day of fasting. Consequently, excretion of the "cellular" macroelement, phosphorus, also had elements of a stress reaction and was probably due to increased breakdown of cellular structures when fasting. Thus, the dynamics of metabolism of cellular macroelements (potassium and phosphorus) were poorer on the 3d-5th days of the "emergency situation" when subjects were fasting than when they used low-calorie rations (300 g chocolate).

The results of these studies warrant the conclusion that, according to subjective state and dynamics of parameters of nutritional status (primarily weight, dynamometry, carbohydrate, fat, amino acid, nitrogen and mineral metabolism), more unfavorable conditions for "survival" are created on a total fast in emergency situations lasting 5 days, particularly on the 4th and 5th days, than with use of low-calorie rations (300 g chocolate).

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EFFECT OF PERIODIC ACCELERATIONS OF 5 G ON KINETICS OF ERYTHROCYTE HEMOLYSIS IN WHITE RATS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 24 Aug 82) pp 60-62

[Article by A. G. Agamalyan and S. S. Oganesyan]

[English abstract from source] The effect of daily acceleration of 5 G applied for 25 min on the kinetic parameters of erythrocyte hemolysis was studied on 30 white Wistar rats. The animals were accelerated in a centrifuge with a 3.25 m rotor for two weeks. Hemolysis was recorded in a modified device that permitted phase analysis of the resultant curves. The selected kinetic parameters varied in a different degree and recovered during readaptation in a nonuniform manner. This is associated with various changes in different components of the regulation of erythrocyte hemolytic resistance.

[Text] Spaceflight factors reduce total plasma volume and red blood cell mass, hemoglobin, hematocrit and percentage of reticulocytes [1-3]. It has been established that there are changes in the direction of microspherocytosis and in shape of some erythrocytes, with decrease in their mass and electrophoretic mobility. Changes in erythrocyte metabolism have also been found: increase in activity of erythropoiesis and decrease in osmotic resistance [3-6]. Artificial gravity, which was produced during the flight aboard Cosmos-936 biosatellite attenuated the decrease in osmotic resistance of white rat erythrocytes which had been caused by weightlessness. In ground-based experiments this parameter rose under the effect of long-term centrifuging of animals at accelerations of 2 G [7]. However, there is no information about the effect of periodic exposure to higher accelerations on erythrocyte resistance to hemolysis.

In order to obtain a fuller description of erythrocyte hemolysis, we [8] modified somewhat the method of acidity erythrograms [9, 10]. Hemolysis curves were submitted to phase analysis.

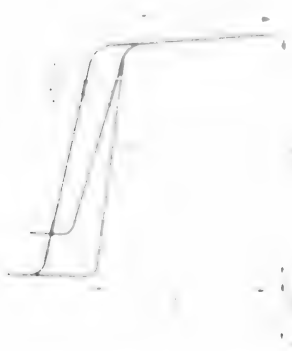
Methods

In our unit, the electric signal is delivered from the photocolorimeter to a KSP-4 automatic recorder, which records the course of hemolysis according to

change in light transmission of a suspension of erythrocytes in hemolytic solution (0.9% NaCl in 15 mM tris-HCl buffer, pH 2.2). A magnetic mixer was installed within the housing of the photocalorimeter to provide for rapid mixing of blood with solution. This enables us to record the process from the moment of adding blood into the tray with a micropipette, as well as to record the curves, not only of acid, but faster osmotic hemolysis.

Estimates of kinetic parameters of hemolysis can be made from the chart strip of the automatic recorder, without resorting to additional plotting of graphs. Hemolysis time can be determined from the graduations on the x-axis if we know the tape feeding rate. Each graduation on the tape's y-axis corresponds to hemolysis of 1% of all red blood cells (graduations from 0 to 100). This makes it possible (as with the method of acid erythrograms) to obtain information about the percentile distribution of erythrocytes according to acid or osmotic resistance.

The following parameters were calculated from the curves of acid hemolysis: t, total hemolysis time; v, rate of hemolysis in cooperative segment; a, depth of hemolysis corresponding to change in light transmission; b, height of hemolysis (residual transmission of light after hemolysis); T, duration of "lag" phase, i.e., time of hemolysis to the start of the cooperative segment, during which there is destruction of erythrocytes with diminished resistance (see Figure). The parameter $\frac{a}{a+b}$ characterizes the ratio of quantity of hemolyzed erythrocytes to their total initial quantity. With relative constancy of the $a+b$ sum, i.e., initial light transmission of the suspension, we can use parameter a in this series of experiments, instead of the above ratio. The a/t ratio indicates overall speed of the process. Self-acceleration of the process in the cooperative segment could be attributed to the effect of substances discharged from erythrocytes that have already undergone hemolysis. It is known, in particular, that hemolysis is catalyzed by hemoglobin and iron without heme from destroyed erythrocytes [11]. It is interesting to note that the rate of osmotic hemolysis for the first 5-10 s, when first-order kinetics are observed, is closely related to change in mobility of hydrocarbon chains of the erythrocyte membrane, but does not depend on osmotic resistance [12]. The described method yields more precise recording of the course of hemolysis, and makes it less time consuming to analyze results.



Averaged curves of course of hemolysis in control group of animals (1), animal group exposed to accelerations (2) and 1-month recovery group (3)

Curve 2 shows parameters of kinetic tracing of hemolysis

In this study we used 30 white Wistar rats, with 10 animals in each group. The control animals made up the first group. The second group of animals were rotated on a specially designed centrifuge with rotor 3.25 m in diameter at 58 r/min (5 G acceleration) for 25 min/day for 2 weeks, with the rotor

of inertial force directed from the head to the tail. The third group consisted of readapted animals, whose blood was tested 30 days after discontinuation of centrifuging. Blood was taken after decapitating animals under ether anesthesia; it was diluted in saline in a 1:4 ratio, with addition of 0.04 mℓ heparin/2.5 mℓ suspension. The samples can be stored for 3-4 h at 4-6°C without change in the main parameters. Hemolysis was recorded at least 3 times for each animal. Statistical reliability was determined by the criterion of Student.

Results and Discussion

Periodic exposure to 5 G for 2 weeks elicited significant changes in several parameters of acid hemolysis (see Table and Figure). There was reliable increase in rate of cooperative phase of hemolysis (by 21.2%) and depth of hemolysis (by 10.9%), with decline of overall hemolysis time (by 11.5%). There was no reliable change in duration of the "lag" phase, which is apparently indicative of lack of changes in ion permeability of erythrocyte membranes. It could also be related to the stability of the erythrocyte population with diminished acid resistance. The increase in rate of cooperative phase and decrease in total hemolysis time are indicative of diminished acid resistance of most erythrocytes, which would appear, at first glance, to be inconsistent with data in the literature concerning increase in osmotic resistance of red blood cells of animals exposed to long-term accelerations of 2 G [7]. The difference is apparently due to differences in magnitude and frequency of exposure to accelerations. In addition, we know that, in some cases, acid and osmotic resistance change differently and even in opposite directions [5]. Hypoxic signs appear in the animals under the effect of a higher gravity field. It was reported that mild hypoxia enhances osmotic resistance of erythrocytes and hyperoxia attenuates it [13]. Severe hypoxia leads to decrease in red blood cell resistance [14, 15].

Effect of periodic and brief exposure to accelerations of 5 G on kinetics of erythrocyte hemolysis in white rats

Parameters of kinetics of hemolysis	Group of animals		
	1st (control)	2d	3d
Rate of cooperative phase of hemolysis v, mm/s	4.62±0.25	5.6±0.3*	5.36±0.2
Total hemolysis time t, s	156±4	138±5*	174±4*
Duration of lag phase T, s	90±1.5	88±2	96±1.5*
Depth of hemolysis a, cm	14.6±0.5	16.2±0.4*	16.25±0.5

* $P<0.05$

As can be seen in the Figure and Table, the kinetic parameters of hemolysis in the recovery group undergo dissimilar restoration. The rate of the cooperative phase and depth of hemolysis did not revert to control values, while total hemolysis time and duration of the lag phase increased reliably, exceeding the corresponding values for the control group of animals. We had demonstrated such a "pendulum" effect in our laboratory, with regard to change in inotropic

effect of calcium ions and catecholamines on isolated myocardial fibers from animals in the same recovery group [16]. The fact that the rate of the cooperative phase does not change reliably in the recovery period indicates that self-acceleration of the process is attributable to changes that are unrelated to distribution of red blood cells according to acid resistance. Apparently there are other factors present, the effect of which is not eliminated in 1 month.

It must be noted that, if we were to judge from the overall rate of hemolysis (V_0), there would be the false impression of complete recovery of erythrocyte resistance after readaptation for 1 month. The value would be 0.936 $mm \cdot s^{-1}$ in the control group of animals, 1.174 $mm \cdot s^{-1}$ in the experimental group and 0.934 $mm \cdot s^{-1}$ in the recovery group. Consequently, phase analysis of hemolysis kinetics provides broader and more detailed information about the course of hemolysis under extreme conditions.

The results indicate that there are different changes in the different kinetic parameters of hemolysis after periodic exposure to accelerations, while their recovery in the readaptation period is not uniform, probably due to dissimilar changes in different elements of regulation of hemolytic resistance of erythrocytes.

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NEURONAL-VASCULAR RELATIONS IN LATERAL GENICULATE BODY AND SUPERIOR COLLICULI OF CATS AFTER EXPOSURE TO ACCELERATIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 18 Aug 82) pp 63-65

[Article by I. V. Boyarkina]

[English abstract from source] Thirty-nine cats were exposed to accelerations of 10 g for one or several days. Their neuronal-vascular relations in the subcortical optic centers were investigated using ink-gelatin injections and Nissl's method. During one-day back-to-chest, chest-to-back and head-to-feet acceleration and many-day head-to-feet and chest-to-back acceleration neuronal-vascular relations decreased, whereas during one-day feet-to-head and many-day, chest-to-back and feet-to-head acceleration they increased. During one-day centrifugation edematous neurons and during many-day centrifugation swollen neurons may occur.

[Text] The importance of studying the structure of the lateral geniculate body (LGB) and superior colliculi (SC) is related to the particular vulnerability of vision [1-3] with exposure to accelerations.

Methods

We conducted our study on 39 cats, 15 of which were used as a control and 24 were exposed to accelerations (12 animals in each series, with 2 animals for each direction of accelerations). In order to create accelerations we used a centrifuge with 2-m radius [4]. In the first series, we created accelerations of 1.1 to 10 G for a total of 17 min (Table 1). In the second series of multiday experiments, accelerations of 2 to 10.2 G for 2 to 7 min were created twice a day at 4-h intervals (Table 2). In order to obtain preparations, we injected India ink with gelatin through the carotid arteries to anesthetized (alcohol, ether and chloroform in a ratio of 1:1:1) animals. The obtained sections (with the exception of "vascular" ones) were stained by the Nissl method. Neuronal-vascular relations in the LGB and SC were studied by a method described previously [4-5]. We examined the following parameters characterizing the relations of neurons to vessels: 1) length of microvessels in a radius of 25 μm from the body of the neuron (large, medium and small); 2) quantity of neurons touching microvessels (out of 10 counted ones); 3) length of neuron-vascular contact in micrometers; 4) size of microvascular loops. We determined the

"critical thickness of nerve tissue" in the LGB and SC. This term refers to the shortest distance between capillaries, which reflects the intensity of metabolic processes in an organ.

Table 1.
Rotation conditions in first series

Accelerations, G	Rotation time, min
1.1	1
2	2
4.4	2
7.2	1
5.5	2
9.2	2
4.4	3
7.2	3
10	1

Table 2.
Rotation conditions in second series

Day of experim.	First exposure		Second exposure	
	accel. G	accel. G	accel. G	accel. G
1	2	3	2	4
2	2	5	3.5	5
3	4.4	4	4.4	5
4	4.4	5	5.5	2
5	5.5	2	5.5	3
6	5.5	3	5.5	2
7	5.5	5	7.2	4
8	7.2	5	7.2	5
9	4.4	7	5.5	4
10	7.2	5	7.2	6
11	9.2	3	9.2	3
12	10.2	4	10.2	3

Results and Discussion

After rotation in the first series of experiments, the density of the vascular-capillary system of the LGB diminishes with all directions of inertial forces (back-chest, chest-back, head-pelvis) with the exception of pelvis-head direction (Figure 1). There is insignificant fluctuation of length of microvessels in the zone of vascularization of large, medium and small cells in the LGB, as compared to the contorl, after accelerations in the pelvis-head direction (457.9±2.9-450.6±1.8 μm) and it decreases somewhat after accelerations in the back-chest (412±1.7 μm), chest-back (420.7±1.2 μm) and head-pelvis (391.8±1.6 μm) directions. Critical thickness of nerve tissue increases after back-chest, chest-back and head-pelvis directions of accelerations and decreases after pelvis-head accelerations. The patterns of change in neuronal-vascular relations in the SC under the influence of 1-day accelerations are similar to those in the LGB. In all cases, in spite of constant architectonics of the LGB and SC, the fine structure of their neurons changes under the effect of accelerations. Edematous cells are encountered in them.

With exposure to accelerations for many days, the density of the vascular-capillary system of the LGB, as well as parameters of neuronal-vascular relations, increase when inertial forces are in the back-chest, feet-head directions and decrease with chest-back and head-feet directions (Figure 2). Evidently, exposure to accelerations for many days elicits major changes in the microcirculatory system of subcortical visual centers. However, in the case of accelerations used for many days, we failed to demonstrate impairment of the integrity of vessels in the form of hemorrhages (exit of injection mass from vessel) even with an acceleration vector in the feet-head direction. This is consistent with the data of N. I. Zotova [6], who found no dye in subcortical elements of the brain, in the perivascular space after numerous exposures to accelerations. The microvascular system of large, medium and

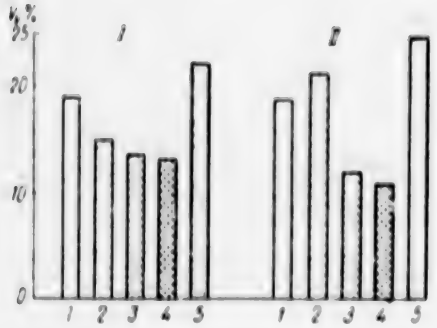

Figure 1.
Volumetric fraction of LGB vessels in 1st and 2d series of experiments with accelerations
1) control
2) chest-back
3) back-chest
4) head-feet
5) feet-head

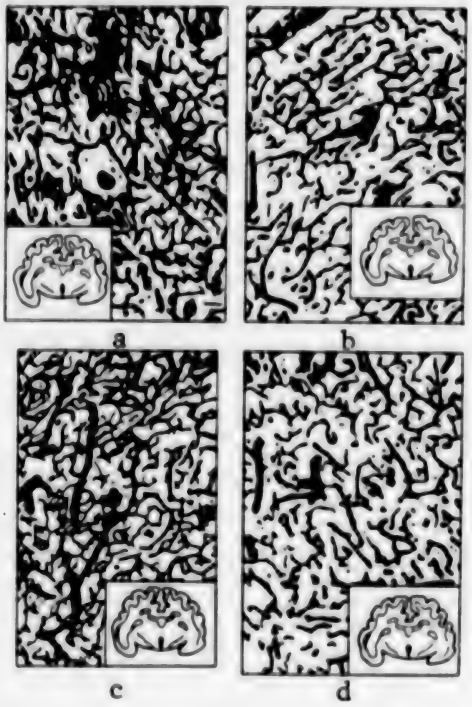

Figure 2.
Brain section at LGB level in many-day experiment with accelerations in back-chest (a), chest-back (b), feet-head (c) and head-feet (c) directions. Injection of vessels with India ink and gelatin; magnification 100×

small cells of the LGB diminishes after accelerations in chest-back and head-pelvis directions, showing virtually no change after exposure to them in back-chest and pelvis-head directions. The minimal distance between capillaries increases with the first two vector directions and decreases with the other two. Such changes were noted in analysis of dimensions of microvascular loops. The number of neurons in contact with microcirculatory vessels, as well as the volumetric fraction of the vascular-capillary bed, increase after accelerations in the back-chest, feet-head directions and decrease after exposure to chest-back and head-feet directions.

In spite of retention of stability of subdivision of cells into layers in the LGB and SC, exposure to accelerations for many days leads to structural changes in the fine structure of their neurons. While in the first series of experiments we encountered edematous changes in cells, in the second there were neurons that were swollen, similar to those observed when their structure is altered due to destruction of cell axon. We can attribute these changes to manifestations observed by B. M. Savin [7] of marked intensification of inhibitory processes in retinal neurons and slowing of synaptic transmission in the optical tract, a distinctive form of functional deafferentation. Thus, our findings are indicative of high plasticity and compensatory capabilities of structures of the visual analyzer when exposed to accelerations.

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UDC: 613.644-092.9-07

STUDY OF VIBRATION RESONANCE FREQUENCIES IN RATS

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[Article by I. B. Ushakov, N. V. Soloshenko and A. P. Kozlovskiy]

[English abstract from source] Using piezoelectric transducers, resonance frequencies of different body parts of rats exposed to whole-body vertical vibration were measured. The exposure was as follows: acceleration--8 m/sec^2, head--75-80 Hz, chest--225-230 Hz, and abdomen--27-29 Hz. An attempt was made to determine roughly an interspecies (man-rat) coefficient with respect to resonance frequencies which was estimated to be 0.2-0.25.

[Text] There is an obvious need for simulating the effects of various factors in experiments with animals, since this yields operational scientific data with variation of the experimental situations over a wide range.

One of the most important and, at the same time, least studied factors, from the standpoint of extrapolating to man the data obtained on animals, is vibration. The search for equivalent conditions of exposure of man and animals to vibration (parameters of frequency, vibration shift, vibration acceleration, duration of exposure, as well as direction and axes of vibration in relation to the body) has failed thus far.

The primary cause of differences between human and animal reactions to vibration is body mass. Differences in mass are reflected in the range of resonance frequencies, at which anatomical structures, organs and systems receive vibrations of maximum amplitude under the influence of the perturbing forces applied to the body. There are only a few works dealing with measurement of resonance frequencies [1-3], and the rat as a species is not mentioned in these studies. There is also insufficient information about resonance frequencies of different parts of the animal body, in particular, the head.

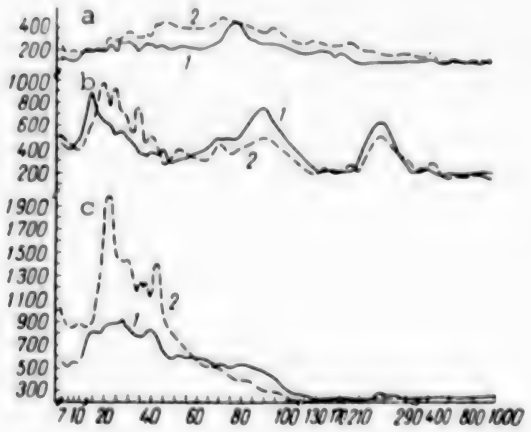
Our objective here was to determine the resonance frequencies of vibration in different parts of the rat body (head, chest, abdominal cavity), as well as to search for possible values for an interspecies man-rat index according to the criterion of resonance frequencies of different parts of the body.

Methods

Measurements were taken on 6 male Wistar rats differing in weight (Table 1). The animals were rigidly immobilized (by means of tape used on the paws and superior incisors) in supine position on the bottom of an "orgalit" chamber attached to a VEDS-1500 vibration table. Piezoelectric sensors were attached to the head, chest and abdominal wall of each live rat and biomanikin (rat cadaver). To calibrate the sensors, we took measurements first on a phantom (rubber balloon with water, with a weight floating in it), and they showed that the piezoelectric transducers used had no resonance of their own up to a frequency of 1 kHz. The irregularity of amplitude-frequency characteristics did not exceed 5%.

For subsequent determination of parameters, the animals were sacrificed by intraperitoneal injection of sodium pentothal at the rate of 100 mg/kg weight without changing the positions of the sensors.

Oscillograms of vibration of the studied parts of the body were recorded on an S1-70 oscillograph for 2 min at each fixed frequency. The graduation of frequencies was determined by the nature of changes in maximum oscillation amplitude: with appreciable change the step was reduced. We expressed the vibrations of parts of the rat body as the product of maximum amplitude of oscillations on the oscillograph screen (in millimeters) multiplied by the indicator of sensitivity of the measuring instrument. The arbitrary amplitudes of oscillation illustrated in the Figure were obtained by multiplying the obtained product by 10^3.



Amplitude of vibration of different parts of the rat body as a function of applied vibration at constant acceleration (8 m/s^2). X-axis, vibration frequency (Hz); y-axis, amplitude of oscillations (arbitrary units)

a) head
b) chest
c) abdominal cavity
1) biomanikin
2) intact rat

Table 1.
Anatomical data on experimental animals (rats) used in this study

Examined object	Mass, g	
	$\bar{X} \pm m$	confidence intervals at $P \leq 0.05$
Whole body	502.7±60.1	348.2—657.1
Head	46.4±4.5	34.8—57.9
Lungs	2.78±0.39	1.78—3.78
Heart	1.86±0.18	1.40—2.32
Liver	14.7±1.47	10.9—18.5
Stomach and intestine	41.2±4.0	36.1—46.3

Acceleration of vibration constituted a constant rate of 8 m/s^2 in our experiments. Oscillograms were recorded 3 times for each rat and biomanikin. As a result of the studies, we obtained curves of amplitude of

oscillations of different parts of the body as a function of vibration frequency (see Figure). In order to determine the effect of change in mass of the tested parts of the body and geometric location of organs and tissues on amplitude and frequency characteristics, we performed the following: injection of 30 mℓ water in the abdominal cavity of an intact rat, injection of 30 mℓ water in the chest of the biomanikin, injection of 36.6 g mercury into the abdominal cavity of an intact rat.

After taking the measurements, we determined the mass of the corresponding parts of the body, as well as mass and volume of internal organs situated within the geometric projection of the corresponding piezosensors: heart, lungs, liver, stomach, intestine (see Table 1).

Results and Discussion

The averaged resonance curves for different parts of the body (see Figure) indicate that there are typical outlines for each of the three locations of the sensory of amplitude of oscillations as a function of vibration frequency: two peaks of maximum oscillations for the "head" and "abdomen" sensors and three for the "chest" sensor" (Table 2).

Table 2. Mean frequencies of vibration at which maximum amplitudes of oscillations (peaks) were observed for different sensor locations

Location of sensor	Object examined	Frequency, Hz		
		first	second	third
		peaks		
Head	Intact rats	29.7±1.7	80±2.9	—
	Biomanikins	28.0±2.7	75.8±3.3	—
Chest	Intact rats	23.8±1.6	81.6±3.6	230±2.5
	Biomanikins	22.7±3.5	78.1±1.3	225±30
Abdominal cavity	Intact rats	29.4±2.6	82.9±1.1	—
	Biomanikins	27.0±3.3	—	—

Injection of 30 mℓ water into the abdominal cavity of an intact rat and 30 mℓ in the chest of the biomanikin elicited the expected shift to the left of peaks of oscillations (in the direction of lower frequency), while injection of 36.6 g mercury into the abdominal cavity elicited appearance of an additional peak at lower frequency. This served as indirect confirmation of the validity of relating the observed oscillation peaks to corresponding parts of the body.

On the whole, oscillation amplitude was higher in biomanikins than intact rats, apparently due to the absence of mechanisms of "physiological damping." The mean frequencies for each of the three peaks (see Table 2) were virtually the same when measured in the biomanikins and intact rats, which confirms the physical essence of the parameter we measured. In view of the minimal and insignificant differences, we shall not make a drastic distinction between these two types of readings.

Table 3.
Correlation between human and rat resonance frequencies (data from the literature and our experimental data)

Object	Man*	Rat	$K=\frac{f_0\ (m)}{f_0\ (r)}$
Whole body (supine)	3–4	22–29	0.15–0.20
Head	20–30	75–80	0.25
Chest	20	80	0.25
Chest wall	60	225–230	0.2
Abdominal cavity	4–8	27–29	0.20–0.25

*Data taken from [1-5]

The maximum amplitude and broadest front of oscillations were recorded with the sensor on the "abdomen" in the range of 20-40 Hz (first peak). It was also noted, but to a lesser extent, for the "chest" sensor. This is probably indicative of the fact that the first weak, which is attributable to resonance of the abdominal cavity, is transmitted by the chest region that is anatomically closely related to it, and the peak is very mild for the "head" sensor.

The second peak of oscillations appears at 75-80 Hz and apparently reflects the resonance frequency of oscillations in the rat head. It can be noted that the signs recorded with the "head" sensor differ substantially from those for the "chest " and "abdomen" sensors. The observed increases in oscillation amplitude (peaks) for the "head" sensor have no marked limits of frequency, amplitude builds up relatively gradually and reaches a maximum at 75-80 Hz. In the other two locations of sensor in this range of frequency we find, on the contrary, a decline of amplitude (see Figure). Evidently, the reaction of oscillation of the rat's head in response to changes in given frequency differs substantially form the reaction of the chest and abdominal cavity.

The third peak, in the range of 225-230 Hz, is manifest when the sensor is on the chest. Its frequency corresponds to resonance characteristics (r = 0.89) of the mass of chest organs (lungs + heart). The data on human resonance frequencies [3, 5] indicate that there are different resonance frequencies for the chest (20 Hz) and chest wall (60 Hz). Perhaps, expressly the second and third peaks under the "chest" sensor correspond to such division. At any rate, the scale principle is retained in this situation (Table 3).

We determined the correlation between mass of organs under the sensors and maximum resonance frequencies, or more precisely, between the logarithms of mass and logarithms of frequency. The obtained coefficient of correlation (r = -0.864) is indicative of a close correlation between mass and resonance frequency in different parts of the rat body.

The resonance frequencies we found for the rat head, chest and abdominal cavity generally conform well to the interspecies (man-rat) functions established in [1, 2] and chest and abdominal cavity resonance frequency as a function of body weight, according to which the resonance frequency of some part of the body is proportionate to its mass in the 1/3d degree. Hence it is obvious that, when changing from one species to another, it is important to take into consideration interspecies coefficient K, which equals the ratio of human resonance frequency to resonance frequency for the given species of animal:

$$K = \frac{f_0(m)}{f_0(r)},$$

where $f_{0(m)}$ is resonance frequency for man and $f_{0(r)}$ is resonance frequency for rats.

Coefficient K includes both differences in mass and all other distinctions of species capable of affecting the values of resonance frequencies. Table 3 shows that coefficient K constitutes a mean of 0.2-0.25.

Thus, we have determined here the resonance frequencies of different parts of the rat body with exposure to whole-body vertical vibration. They constituted 75-80 Hz for the head, 225-230 Hz for the chest and 27-29 Hz for the abdominal cavity. An effort was made to make an approximate estimate of the interspecies (man-rat) coefficient according to the criterion of resonance frequencies, and it was found to be 0.2-0.25.

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COMPARATIVE CHARACTERISTICS OF ERYTHRON REACTIONS TO HYPOXIC HYPOXIA, IMMOBILIZATION AND HIGH-INTENSITY STATIONARY MAGNETIC FIELD

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 23 Feb 82) pp 68-71

[Article by S. A. Grebennikov and A. D. Pavlov]

[English abstract from source] The comparative study of the effects of hypoxic hypoxia, immobilization and a constant magnetic field of high-strength (80 and 240 kA/m) has shown that the latter exerts an erythropoiesis-stimulating effect in rats. This manifests as an increase in the absolute count of reticulocytes in blood and in the count of erythroid cells in bone marrow 72 hours after the 4-hour exposure to a constant magnetic field.

[Text] The data in the literature are indicative of changes in functional state of erythron under the effect of a stationary magnetic field (SMF) [1, 2]. However, the mechanisms of erythron reactions to SMF are still unclear. Our objective here was to investigate the mechanism of erythron reaction to SMF by comparing its effect to the effects on erythropoiesis of a specific, erythropiesis-stimulating factor (hypoxic hypoxia), as well as a factor that is nonspecific for erythropoiesis (immobilization).

Methods

Experiments were conducted on 279 mongrel male and female white Wistar rats weighing 150-210 g. The animals were placed in vertically oriented SMF in plastic containers, with 5 animals in each, all at the same time of day. The SMF intensity constituted 80 and 240 kA/m; intensity gradient did not exceed 4% and pulsation of the variable component of current (100 Hz) constituted 0.05%. The working space between the poles was 120 mm and their area was 240×260 mm. Field intensity did not exceed 120 A/m in the place where we kept control animals. The choice of specific physical parameters of the SMF used was based on the needs of space biology and medicine [1, 3]. To simulate hypoxic hypoxia, the animals were kept in an inflow-exhaust pressure chamber at an "altitude" of 6000 m. Immobilization was effected by securing the animals on an operating table with the belly up. In all cases, exposure to the factors lasted 4 h.

We determined the erythrocyte content per unit blood volume, hematocrit and absolute reticulocyte count. Total erythroid cellularity of bone marrow (TECB) was determined according to incorporation of ^{59}Fe in erythroid cells of bone marrow and erythrocytes of peripheral blood [4, 5]. We injected ^{59}Fe in the caudal vein in a dosage of 10 μCi/kg weight 20 h before assaying TECB. Bone marrow was flushed out of the femurs with 1.1% NaCl solution and eluated until radioactivity disappeared from the supernatant. We then counted cells in the end cellular suspension, in a Goryayev chamber using 0.1% solution of bright cresyl blue to stain the cells and reduce their aggregation. Blood samples were taken at the same time as the bone marrow samples, they were treated the same way, but using isotonic solution for eluation. We measured radioactivity of the end cellular suspension of blood samples and bone marrow on a well-type scintillation USD-1 counter using a PS-10000 conversion instrument and 20026 radiometer. TECB was calculated using the following formula:

$$TECB = \frac{N \cdot C}{C_N}$$

where N is cellularity of marrow samples, C_N is radioactivity of marrow samples and C is total radioactivity of bone marrow, which was considered to equal radioactivity of peripheral blood erythrocytes 12 days after injection of ^{59}Fe blocking its recirculation with Fe^{2+}. We determined the values for the parameters under study 1, 24, 72 h and 10 days after exposure to the different factors.

Results and Discussion

Our study of cell composition of peripheral blood revealed an increase in absolute quantity of reticulocytes 1 and 72 h after exposure to SMF of 80 and 240 kA/m. Immobilization elicited an increase in absolute quantity of reticulocytes 1 h after exposure to it. Hypoxia led to increase in reticulocyte content of peripheral blood 24 h after exposure, with a maximum at 72 h (Table 1). Eruthrocyte count and hematocrit did not differ from control levels at all measured times after hypoxia, immobilization and SMF.

The increase in absolute quantity of reticulocytes in the peripheral circulation is an indication of stimulation of erythropoiesis. However, as demonstrated previously [6, 7], only reticulocytosis of peripheral blood combined with an increase in erythroid cellularity of bone marrow is an indicator of stimulation, since it is possible for there to be an increase in quantity of circulating reticulocytes without increase in erythroid cellularity of marrow. Such reticulocytosis was called redistributing, and it is not indicative of actual intensification of erythropoiesis [6, 7]. For this reason, it is difficult to assess reticulocytosis without analyzing erythroid cellularity of bone marrow.

As can be seen in Table 2, an increase in erythroid cellularity of bone marrow was noted 72 h after exposure to hypoxia and SMF. Consequently, reticulocytosis combined with increased erythroid cellularity of bone marrow 72 h after exposure to hypoxia and SMF is an indicator of stimulation of erythropoiesis.

A decrease in TECB was observed 1 h after immobilization and SMF. At this time, peripheral blood showed an increase in reticulocyte content. Probably

the described changes in quantity of circulating reticulocytes and TECB are attributable to exit of bone marrow reticulocytes into the peripheral circulation under the effect of the above-mentioned factors, since it is known that reticulocytes constitute up to 50% of the population of erythroid cells in bone marrow [8] and their migration into peripheral circulation has an appreciable effect on TECB.

Table 1. Reticulocyte content of peripheral blood ($\cdot 10^9/\ell$) under the effect of SMF, hypoxic hypoxia and immobilization

Factor	Time after exposure, h				
	1	24	72	240	control
SMF (80 kA/m)	266.1±31.51*	198.1±19.62	378.0±24.55***	216.4±31.52	147.3±17.52
SMF (240 kA/m)	282.2±23.35**	200.5±18.33	402.1±37.11***	192.6±20.87	—
Hypoxia	166.3±17.25	215.3±13.11*	578.2±43.12***	201.8±23.66	—
Immobilization	442.3±37.16***	206.7±22.22	122.7±15.66	168.7±19.39	

Note: In all instances, we conducted 5 experiments; time of exposure was 4 h. Here and in Table 2: *P<0.05, **P<0.01, ***P<0.001.

Table 2. TECB and radioactivity of blood samples exposed to hypoxic hypoxia, SMF and immobilization

Factor	Time after exposure, h			
	1		72	
	TECB, $\cdot 10^8$ cells	C_{Kr}, counts/min/0.1 mℓ erythroc.	TECB, $\cdot 10^8$ cells	
Control	2,08±0,113 (100±5,4)	2654.0±544.54 (100±20,5)	— —	
Hypoxia	2,02±0,049 (97,0±2,36)	1830.3±76,28 (69,0±4,16)	3,92±0,249*** (188,5±6,37)	
SMF (80 kA/m)	1,70±0,112* (81,7±6,59)	— —	2,73±0,211* (131,3±7,73)	
SMF (240 kA/m)	1,63±0,122* (78,4±7,49)	7768.3±813.48*** (292,7±10,47)	2,83±0,304* (136,1±10,74)	
	1,45±0,070** (69,7±4,83)	8139.6±1006.82** (306,7±12,36)	2,33±0,211 (112,0±9,06)	

Note: In all instances, 5 experiments were performed and bone marrow from 5 animals combined in each; percentages are given in parentheses.

Table 2 also lists data about radioactivity of blood samples 1 h after exposure. As indicated above, ^{59}Fe was injected to experimental animals 20 h before use of the factors. Thus, by the time of exposure all of the marrow erythroid cells were labeled with ^{59}Fe [4], and the increase in radioactivity of blood samples under these conditions after 4-h exposure was due to exit of bone

marrow reticulocytes into the peripheral circulation. This made it possible to rule out a possible reduction in number of circulating reticulocytes during exposure to hypoxia that would be related to their faster maturation [9, 10], as well as to check radiologically for the presence of redistributing reticulocytosis 1 h after exposure to the above factors.

Thus, immobilization elicited a decline of TECB and increase in radioactivity of blood samples 1 h after exposure, without causing change in erythroid cellularity of bone marrow at other tested times. Hypoxia led to increase in TECB 72 h later, but did not cause decline of TECB and increase in radioactivity of blood samples after 1 h. Exposure to SMF of 80 and 240 kA/m led to similar erythron reaction in the form of decline of TECB with increase in radioactivity of blood samples after 1 h, with subsequent increase of TECB 72 h after exposure.

Analysis of the findings indicates that hypoxia and SMF elicit a genuine intensification of erythropoiesis, as assessed by the increase in absolute quantity of reticulocytes in the peripheral circulation and erythroid cellularity of bone marrow 72 h after exposure. Reticulocytosis combined with decline of TECB was noted 1 h after exposure to SMF and immobilization. This decline is probably indicative of the redistributing nature of reticulocytosis. The decline of TECB was associated with increase in radioactivity of blood samples and, since bone marrow was totally labeled with ^{59}Fe, this could be due only to exit of bone marrow reticulocytes into peripheral circulation.

In our experiments, hypoxic hypoxia did not elicit redistributing reticulocytosis in rats (at parameters of 6000 m "altitude" and 4-h exposure) 1 h after termination of exposure. A build-up of reticulocytes under hypoxic conditions was demonstrated after 24 h, with maximum reticulocytosis 72 h after exposure. These data do not rule out, however, the possibility of redistributing reticulocytosis in the case of specific, erythropoiesis-stimulating factors. With such factors (injection of phenylhydrazine, blood-letting, etc.) redistributing reticulocytosis has been described [6, 7]. But it is apparent from the literature that the question of mechanism of redistributing reticulocytosis under the effect of factors that are specific and nonspecific for erythropoiesis has not been submitted to special investigation.

It can be concluded from the foregoing that hypoxia, which is a specific stimulator of erythropoiesis, elicits intensification of the latter at times that are similar to its intensification under the influence of SMF. This similarity can probably be interpreted as confirmation of the hypoxic effect of SMF [11]. Immobilization, which elicits marked changes in neurohormonal status of experimental animals (rats), does not have a specific (hypoxic) effect on erythropoiesis. Thus, the redistributing reticulocytosis observed under the effect of SMF and immobilization can be evaluated as nonspecific.

In conclusion, it should be noted that a comparative study of the effect on erythropoiesis of SMF, hypoxia and immobilization had not been made before.

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UDC: 574.685

PLANT WASTE PROCESSING ON A SOLID SUBSTRATE FOR A BIOLOGICAL LIFE-SUPPORT SYSTEM FOR MAN

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 4 Mar 83) pp 71-74

[Article by Ye. Ya. Shepelev, Yu. I. Shaydorov and V. V. Popov]

[English abstract from source] The level of waste processing and utilization of the resultant products in a biological life support system largely determines the degree of system closure. Straw degradation in the humus and an inert substrate was studied when straw was introduced once a month during 3 years. Following 5-6 cycles of straw degradation in the humus, there developed a stable soil biocomplex that functioned as a self-regulation system. After adaptation and completion of the soil biocomplex formation straw degradation in the humus developed at a rate that provided its complete degradation within a certain greenhouse area.

[Text] One of the important problems of cosmonautics is to provide a habitable environment in space stations that would satisfy the metabolic requirements of man. A promising means of solving this problem is to develop a biological life-support system (BLSS) for man. Together with all of the conditions in a pressurized spacecraft cabin, it is viewed as a rather well-developed ecosystem with relatively closed cycle of elements, into which there is complete inclusion of man's trophic relations [1-3].

According to the specifications for BLSS based on ecological mechanisms, processes of microbiological decomposition of organic waste should occur in part in the root zone of plants with direct contact with the rhizospheric microflora. This can be done by raising plants in a substrate that has the biological functions of real soil [4]. In the multifunctional community of soil organisms, which is complex in composition and distribution in the habitable environment, a considerable part is played by ecological regulatory mechanisms that arise in the system proper. Self-organization, self-propagation, self-regulation and optimization of trophic and other relations are inherent in such communities [5].

Combining the processing of organic waste and raising plants would make it possible to create a multifunctional BLSS "element," in which there could be

occurrence simultaneously of such processes as recovery of plant biomass, decomposition and transformation of organic waste, providing plants with mineral and biologically active nutrients, self-purification of substrate to remove microorganisms pathogenic to man and plants, detoxification of a number of toxic agents, self-reproduction of the basic biological properties and functions of the substrate [6-8].

In combining microbiological decomposition of waste and plant growing, it is necessary to have coordinated rates of formation and decomposition of waste, which constitutes 28-33 g dry mass per square meter of greenhouse area per day.

In order to make an experimental study of some of these processes, long-term experiments were set up involving periodic addition of plant residue to a solid substrate.

Methods

In these experiments, we used the straw of wheat raised hydroponically in a greenhouse. Since the C:N ratio was favorable for microbiological decomposition of straw [9], no additional nitrogen was used. Ground straw was placed in a layer in a substrate at a depth of 3-5 cm, with 70 g dry mass per container (2 kg). Straw was decomposed in vegetation containers placed on a shelf with a fluorescent lamp fixture. In the experiments we used hothouse humus and a synthetic substrate, polyethylene granules. We added 10 g dry humus mass to each container to intensity decomposition in the granules. The substrates and irrigation water were continuously aerated [10]. Wheat plants were raised in some of the containers to the age of 10 days. In order to determine exchange of gases (O_2 uptake and CO_2 output) the containers were put in sealed chambers. The experiment lasted 3 years. In this time, we added 1.2 kg straw or 36 g/m^2 per day to each container (per 2 kg substrate), which is commensurate with the rate of its formation in a greenhouse.

Results and Discussion

The rate of CO_2 output after 14 months of the experiment at different stages of decomposition of straw per cycle was virtually the same in humus and the granules. In both instances, the rate of CO_2 output 2 days after addition of straw increased by 10 times (from 200-220 to 2200-2300 mℓ/day). By the 10th day, output rate dropped to 500-700 mℓ/day and then, up to the 30th day of decomposition, we observed gradual decline of CO_2 output to the initial level.

Figure 1 illustrates the dynamics of substrate mass in the course of the experiment. As we see, straw breakdown in the granules was slow for 12-14 months, and as a result there was accumulation of organic matter in the substrate. This can probably be attributed to the fact that the destruction soil biocomplex was not yet formed. In subsequent years, all of the added straw was decomposed in one cycle, as a result of which substrate mass remained at virtually the same level. Organic matter content became stable and constituted about 6% of total substrate mass.

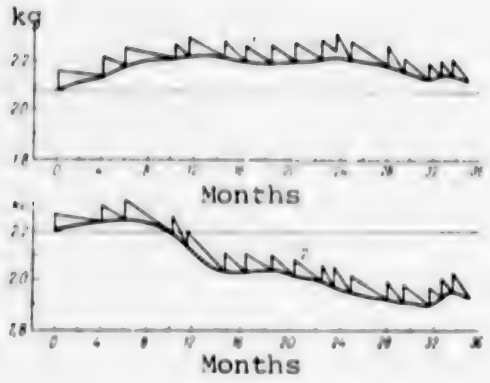

Figure 1.
Dynamics of substrate dry mass with regular addition of straw
1) polyethylene granules 2) humus

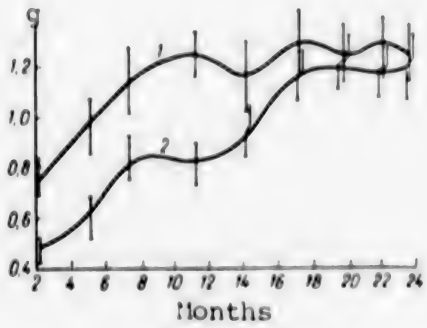

Figure 2.
Dynamics of dry mass of wheat plants (10 days old) during straw decomposition in substrates (Dry mass/100 plants, g)
1) humus
2) polyethylene granules

The period of formation of adapted soil biocomplex in humus lasted 6 months. In this time, due to incomplete decomposition of straw, there was insignificant increase in substrate mass. In the following months, the decline of substrate mass per cycle of decomposition exceeded the mass of added straw as a result of decomposition of organic matter contained in the humus. By the end of the 3d year the rates of addition of straw to humus and of its decomposition were equalized.

Influence of organic matter in aqueous extract of substrate on growth of radish seedlings (average from 3 cycles of decomposition, % of control)

Concentration of dissolved organic matter, mg/ℓ	Seedling length		Root length	
	$X \pm m$, %	t_d	$X \pm m$, %	t_d
Humus extract				
0	100.0±3.7	—	100.0±6.1	—
20	150.7±3.5	9.9	182.7±7.6	8.4
70	154.5±6.1	7.6	199.6±8.3	9.7
200	168.9±6.0	9.2	220.9±5.7	14.5
0 + NaCl—5 g/ℓ	100.0±3.9	—	100.0±2.7	—
70 + NaCl—5 g/ℓ	126.4±5.1	4.1	113.3±6.3	1.9
Granule extract				
0	100.0±2.8	—	100.0±3.3	—
425	129.0±4.3	5.7	111.4±4.2	2.1
600	187.6±4.4	16.8	203.0±7.8	12.1
0 + NaCl—5 g/ℓ	100.0±5.8	—	100.0±8.3	—
425 + NaCl—5 g/ℓ	127.6±5.8	3.4	139.2±10.7	2.9

The dynamics of the microflora after the process came to a stationary mode were fluctuating, and corresponded to the decomposition cycles. As a rule

there was an increase in number of microorganisms after each addition of straw, and it reached a maximum on the 12th-20th day of decomposition. Their number dropped to the initial level by the 30th day. Cellulose-attacking microorganisms and fungi were exceptions, and the fluctuations in their number per decomposition cycle were insignificant.

Considering the substantial role of invertebrates in formation of a soil biocomplex, processes of decomposition and transformation of organic matter [11, 12], we added to each container 30 rainworms and 250 enchytraeids. The number of rainworms became stabilized in humus after 15 months, constituting an average of 70 per container. The number of enchytraeids fluctuated throughout the experiment and had a tendency toward some decline at the end of the study. Already after 4 months, the number of rainworms in granules persisted for 20 months and the number of enchytraeids for 10 months. The reduction and then disappearance of large invertebrates in the granules could be related to the relatively low organic matter content of the substrate. Stabilization of number of rainworms and enchytraeids in humus in the second half of the experiment indicates that the formed sizes of populations of these animals were above the critical levels with the given volume of substrate and its properties.

Aqueous extracts of substrates were obtained after the straw decomposing processes arrived at stationary conditions: after 14, 16 and 18 experimental months. The results of analyses revealed that there is formation of considerably more soluble organic matter in granules in the course of straw decomposition than in humus. Although the concentration of organic matter in the humus extract was almost one-tenth the concentration in granules, optical density was much higher, which could be related to formation of humic acid differing in degree of "maturity" [13, 14]. The organic matter contained in aqueous extracts stimulated growth of radish seedlings and enhanced their resistance to toxic concentrations of sodium chloride (see Table).

The observed effects could be related to the presence of humic substances, the stimulating and protective effects of which have been confirmed in many studies [15, 16].

Determination of increment in wheat plant biomass revealed that minimal plant productivity was observed in the first cycles of straw decompositon (Figure 2). Productivity of plants raised on humus increased up to the 12th month of the experiment and on granules up to the 20th month. After the 20th month (after 8 cycles of decomposition), increment of plant biomass on both substrates became stabilized and about the same. Depression of plant grown in the first few cycles of straw decomposition had been observed repeatedly by researchers, including P. A. Kostychev [17], and it is attributed to immobilization of nitrogen and formation of toxic products of partial decomposition of straw [18-20].

Thus, when straw is added systematically to humus, a stable soil biocomplex is formed after 5-6 decomposition cycles under artificial conditions, and it functions on the basis of self-regulation. After a period of adaptation and completion of formation of the soil biocomplex, the rate of decomposition of straw in the substrate becomes commensurable with the rate of its formation in the same area or volume of greenhouse substrate.

Raising the question of reproducibility under artificial conditions of the basic biological functions of natural soil is, in our opinion, not only warranted but inevitable, if we have in mind the continuous cultivation of plants for many generations in an ecosystem with relatively closed cycle of elements. Perhaps the problem of degree to which the cycle of elements is closed in BLSS of space stations has quite a few parallels with the problem of degree to which the cycle is closed in agrocenoses.

The stability of natural biogeocenoses is largely (if not entirely) determined by the degree to which trophic chains in them are closed. We believe that modern agrocenoses also lose their spontaneous resistance due to a break in the direct relations in the plants-animals-plants system.

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CLINICAL STUDIES

UDC: 613.693-07:616.133.33-004.6-036.15-07

DETECTION OF LATENT ATHEROSCLEROTIC STENOSING LESIONS TO GREAT VESSELS OF THE HEAD IN FLIGHT PERSONNEL

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 18 Nov 82) pp 75-77

[Article by B. Kh. Semenov, L. V. Agapova, L. A. Zhevlakova and B. I. Parmenov-Trifilov]

[English abstract from source] In order to detect stenotic lesions of cerebral large vessels, 207 subjects, primarily pilots, were examined by ultrasonic Dopplerography. The first group with cerebral atherosclerosis at stage I included 90 pilots; 20 of them (22%) showed signs of stenotic lesions of the carotid and spinal arteries. The second group with cerebral atherosclerosis at stage II-III included 117 subjects; 14 of them exhibited interior carotid artery occlusion and 49 stenosis of one or several large vessels. Using clinical data, it was concluded that latent stenosis of cerebral large vessels are frequent in crewmembers even at early stages of cerebral atherosclerosis and, therefore, may be risky for flight safety. Ultrasonic dopplerography, being a fairly simply and accurate technique to detect stenotic vessels, is recommended for large-scale examination of the flying personnel with cerebral atherosclerosis.

[Text] Cerebrovascular diseases make up one of the most difficult areas of expert medical certification of flight personnel (EMC) [1]. One of the causes of early insufficiency of cerebral circulation could be morphological changes in cerebral and extracerebral vessels. As shown by studies [2-5], atherosclerotic changes, stenosis of carotid and vertebral arteries often occur in latent form, without noticeable clinical manifestations, and this is due to the slow development of the atherosclerotic process in vessels.

From the moment an atherosclerotic plaque is formed in a cerebral vessel and until its lumen is 50-70% occluded, there is usually latent stenosis, which correlates with some symptoms of psychological deficit, insignificant decline of mental work capacity and mild neurasthenic signs, which are consistent with the symptomatology of early cerebral atherosclerosis [6]. As a result of change in cerebral hemodynamics in flight personnel, erroneous actions are possible in flying an aircraft.

Collateral circulation plays a large part in compensation of cerebral hemodynamics: it can lead to formation of occlusions in one or even several great vessels of the head manifested by minimal clinical symptoms [4], which are consistent with the syndrome of early manifestations of cerebral circulatory deficiency. Such forms of lesions to the great vessels of the head, which are obscured by powerful collateral circulation, are a great threat to the safety of flights in view of the potential possibility of an acute breakdown of cerebral hemodynamics.

As it has been established by clinical studies of recent years [2, 5], in the presence of cerebral atherosclerosis the great vessels of the head are stenosed the most often. Bifurcation of the carotid arteries, ostia of the vertebral and carotid arteries are the typical locations of stenosis.

At the present time there are two instrumentation techniques for testing the condition of great vessels of the head, which yield reliable information. We refer to cerebral angiography and ultrasonic Doppler cardiography (USDG). The technique for angiography is rather complicated, it requires special x-ray equipment and trained personnel, while USDG is a nontraumatic method of examination that is technically simple, safe to the subject and highly informative, so that it can be used under polyclinic conditions for mass-scale screenings.

Methods

We examined 207 people with cerebral atherosclerosis (CA) by the USDG method. The subjects were arbitrarily divided into two groups. The first (90 people) consisted of flight personnel 37 to 58 years of age with early, stage I CA. Clinical examination revealed the metabolic biochemical disturbances inherent in atherosclerosis, as well as hypertonus or dystonia type changes in the rheoencephalogram (REG), mental disorders (disorders referable to memory, attention, spatial imagination, visual-motor coordination) and diffuse microneurological symptoms without prolapse [?] symptoms. Some subjects presented different neurasthenic complaints.

The second group (117 people) consisted of former flight personnel and patients under observation for cerebrovascular atherosclerotic lesions (stage II-III CA with focal neurological symptoms). The diagnosis of stenosing lesion to extracranial parts of the carotid and vertebral arteries had not figured in any of the cases when admitted to the hospital.

USDG of the carotid and vertebral arteries and palpatory examination of the carotid, temporal and radial arteries were performed on all individuals in both groups; auscultation of carotid and subclavian arteries was performed in 25 patients.

USDG was done using Dyna and Delalande Electronique (France) instruments. We used sensors with a working frequency of 4 mHz. Linear velocity was measured over the common carotid arteries (2 cm below the bifurcation), terminal branches of the ophthalmic arteries--supratrochlear arteries (in the region of the medial canthus) and vertebral arteries (behind the mastoid process on the level of C_2). Concurrently, we performed compression tests on the common

carotids (at the level of C_6 vertebra) and branches of the external carotid. Detection of marked asymmetry in linear velocity of blood flow over the common carotids (over 30%), supratrochlear (over 40%) and vertebral (over 50%) arteries, in addition to other concomitant signs, served as grounds to suspect vascular stenosis. When recording retrograde blood flow through the supratrochlear artery, in the presence of concomitant signs, it was concluded that the homolateral internal carotid was occluded. A series of compression tests enabled us to single out the principal vessel that provided collateral circulation in the presence of occlusions of the internal carotid. We observed no complications during performance of USDG.

Results and Discussion

The Table lists data on USDG and palpatory examination of great vessels of the head. USDG yielded data indicative of stenosis of a major vessel in 20 pilots with the early stage of CA (virtually every 5th one). Distinct weakening (or absence) of pulsation in the carotid and temporal arteries was demonstrated in five patients. The palpation and USDG findings coincided (in part or completely) in three cases.

Results of examining great vessels of the head in individuals with CA

Diagnosis	Number of patients	Changes detected by USDG				Weakening (or absence) of pulsation detected by palpation		
		stenosis of		occlusion of				
		carotid	vertebral	carotid	vertebral	carotid	temporal	radial
		arteries						
CA stage I	90	16	3	1	-	2	3	2
CA stages II & III	117	44	21	14	3	19	3	3

Stenosing lesion to the carotid arteries was found in 63 of the patients with CA stage II-III. In 14 of these cases, the findings were indicative of occlusion of the internal carotid arteries: well-marked retrograde flow through the supratrochlear arteries of the orbital anastomosis. In 19 cases there was combined lesion to the vertebral and carotid arteries.

Palpation and auscultation of great vessels revealed changes that coincided with USDG findings in most cases. Hence, the two examination methods indicated are informative enough for diagnosis of latent stenosis of carotid arteries.

Thus, USDG enabled us to detect latent stenosing processes in great vessels of the head among flight personnel with both the early, first stage of CA and the second and third stages, where occlusive lesions to the carotid and vertebral arteries on the neck in over half the patients were the cause of transient and acute disturbances of cerebral circulation.

We submit below one of the case histories.

G-v, flight commander of a TU-154 aircraft, 45 years of age, was deemed in good health by the expert medical commission for certification of flight personnel from 1955 to 1977. In 1977, the diagnosis of aortic atherosclerosis was made. In February 1980 he underwent a scheduled work-up at the hospital.

Neurological status revealed anisocoria (less on the right than on the left) and a slight difference between rimae (less on the right). Weaker pulsation in theright carotid. Blood pressure in brachial arteries: 110/80 mm Hg on the right, 130/80 mm Hg on the left. Normal skull x-ray. X-ray of the cervical spine showed intervertebral osteochondrosis. Eyegrounds: distinct margins of optic nerve disks, pink in color, no change in caliber of vessels. High blood cholesterol ($324^0/_{00}$) and β-lipoproteins ($926^0/_{00}$). The EEG shows mild diffuse changes in bioelectrical activity of the brain in the form of some disorganization of α-rhythm.

The REG of the right hemisphere is indicative of diminished elasticity of the vascular wall with increased vascular tonus; these changes are more prevalent in the basin of the right internal carotid with diminished blood supply in the same system.

Psychological examination: satisfactory recall of meaning and range of visual perception, some instability of attention, no difficulty in development and alteration of intellectual skulls, average rate of mental activity.

The pilot endured well a submaximum physical load on a bicycle ergometer (1040 kg-m/min) with adequate pulse and blood pressure reactions. He tolerated well an "ascent" to 5000 m in a pressure chamber.

Ultrasonic Doppler cardiography of the carotid, vertebral and subclavian arteries revealed a marked occlusive processes in the brachiocephalic artery with a subclavian steal syndrome on the right.

Diagnosis: atherosclerosis of the aorta, atherosclerosis of branches of the aortic arch--occlusion of brachiocephalic trunk with compensation of peripheral circulation. Atherosclerosis of cerebral vessels without clinical signs of impairment of cerebral circulation, with compensation of neurological and mental activity.

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UDC: 629.78:612.824.1-08:531.719.35

BIOECHOLOCATION METHOD FOR INVESTIGATION OF PARAMETERS OF INTRACRANIAL CIRCULATION OF BLOOD AND FLUID IN MAN

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 13 Dec 82) pp 77-81

[Article by L. G. Simonov]

[Text] Spaceflights are associated with changes in hydrostatic pressure, with drop to zero in weightlessness, which causes redistribution of body fluids and elevation of venous pressure in the upper part of the human body [1].

The observed blood pressure elevation in the jugular vein, by a mean of 6 mm Hg, leads to increased pressure in the cranial cavity which, in turn, has an adverse effect on intracranial circulation [2-4].

For this reason it is necessary to work out methodological approaches to noninvasive evaluation of parameters of intracranial blood and fluid circulation in man under conditions simulating the effects of weightlessness on man, or during actual spaceflights.

There are grounds to expect that data can be obtained about changes in pressure in the cranial cavity by means of analysis of amplitude and phase characteristics of signals from intracranial structures using ultrasonic bioecholocation of the brain [5-13]. We have investigated here this possibility on healthy subjects and patients with cerebral lesions, with placement of the ultrasonic sensor in the region of the frontal eminence and recording the echo signal from the occipital bone. We examined the patterns of change in signal characteristics of healthy subjects in different experimental situations and in the patients we studied the link between the indicator of pulsed attenuation of the signal and cerebrospinal pressure measured by the direct method.

Methods

The existing methodological approaches of echoencephalography [14] make it possible to record signals from such pulsating structures as vessels [15, 16], ventricular walls and septa [6, 7, 9, 10, 17] with the sensor placed on the temporal part of the head.

In this study, we took soundings in the forehead-occiput direction, parallel to the midline of the skull, with placement and attachment of the ultrasonic

sensor in the region of the frontal eminences and registration of the reflected signal from the occipital bone (Figure 1a and 1b).

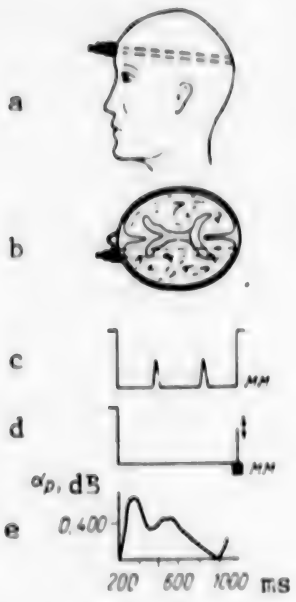

Figure 1.
Distinctions in recording echo signal
a, b) location of sensor and direction of locating: side and top views, respectively
c) base pattern on instrument cathode-ray tube
d) same after lowering instrument amplification in order to get signal from occipital bone of 35-40 mm (square-wave strobe is shown under signal, which permits channeling signal amplitude changes to automatic recorder)
e) pattern of one cycle of recorded pulsation as a function of time

With placement of the sensor on the frontal bone in the region of the frontal eminences (see Figure 1a), the sonic beam crosses the entire cerebral hemisphere, is reflected in the occipital bone and returns in partly scattered form. There are intracerebral structural elements in the path of the sounding beam (1.76 MHz) in this sounding direction after the frontal bone: arteries, veins, body and cornua of the lateral ventricles (see Figure 1b).

The USG-1 ultrasonic sphigmograph [18] makes it possible to isolate (strobe) and channel to the automatic recorder any of the pulses formed at the interfaces. The last pulse is a signal from the occipital bone, the amplitude of which is higher than all the other signals (Figure 1c). By setting the level of this signal on the oscilloscope screen in the range of 35-40 mm (Figure 1d), we were able to record it from two outputs at the same time. One of the outputs is intended for recording the constant component on a type KSP automatic recorder with chart paper feed rate of 1.5 mm/s, and the other for recording the variable component (pulsation) at tape feeding rate of 25 mm/s. It is necessary to record the constant component in order to examine various slow waves and the variable one to study waves related to cardiac function in order to analyze the amplitude and phase characteristics of pulse curves. A pulse curve that resembles a sphygmogram or rheogram was obtained as a result of continuously recording the signal at a tape feed rate of 25 mm/s (Figure 1e). The slow and fast (pulse) waves recorded by this method are apparently due to change in correlation between absorbed and reflected ultrasonic energy at the interfaces (brain tissue--cerebrospinal fluid) during the oscillations in the brain elicited by hemodynamic and cerebrospinal fluid dynamic processes and, in particular, by pulsed oscillations of blood volume in the brain. When the sensor is applied by the proposed method, oscillations of the lateral ventricle apparently make a substantial contribution to modulation of the pulse reflected from the occipital bone. Change in slope of the anteroposterior fronts of the lateral ventricle is probably the cause of signal modulation in the pulsed cycles.

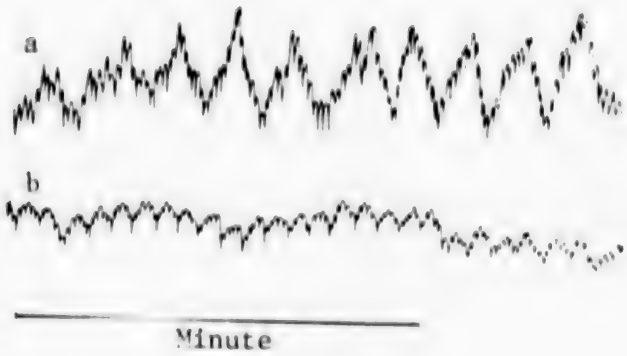

Figure 2.
Pulse, respiration and vasomotor waves recorded on essentially healthy subjects
a) subject B, 21 years old (woman)
b) subject G., 18 years old (woman)

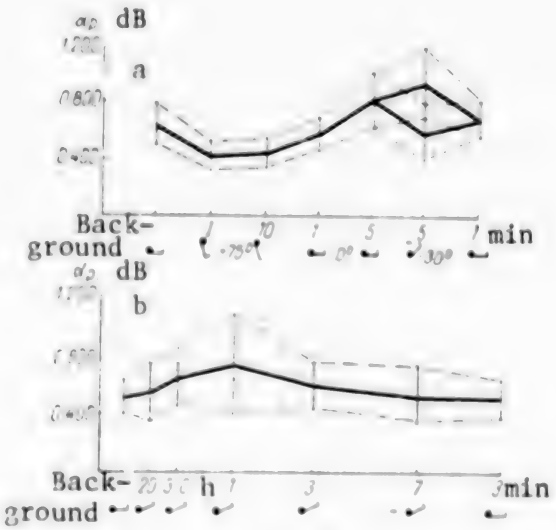

Figure 3.
Changes in indicator of pulsed attenuation of ultrasound (α_p) during orthostatic and antiorthostatic tests (a) and antiorthostatic hypokinesia (b)

The magnitude of attenuation was determined in our studies using the formula proposed by G. S. Stryukov [11]:

$$\alpha = \frac{2l_0 \cdot \alpha_0 \cdot A_0}{l \cdot A} \quad (\text{dB/cm})$$

where α_0 = 2.6 dB/cm, is attenuation in the standard; A_0 is the level of the reflected signal in sounding the standard (in graduations on dial of attenuator), l is the distance to the inside surface of the occipital bone determined on dial in forehead-occiput direction (cm), A is the level of signal reflected from occipital bone with sensor on forehead (in graduations on attenuator dial).

We calculated pulsed attenuation of ultrasound using the formula:

$$\alpha_p = 20 \log \frac{A+\Delta A}{A} \quad (\text{dB})$$

where A is the level of the reflected signal displayed in all tests on the screen with a height of 40 mm and ΔA is pulsed change in level of reflected signal (mm).

In order to test the proposed method we conducted self-experiments and also tested 60 healthy subjects 25 to 45 years of age, as well as 8 neurosurgical patients. The healthy subjects were examined at rest, during postural tests, antiorthostatic [head-down tilt] hypokinesia and with use of lower body negative pressure (LBNP). The neurosurgical patients were examined during diagnostic tests associated with controlled change in cerebrospinal pressure, during which they were in horizontal position, on their side. Saline was injected in drops into the lumbar canal with monitoring on a pressure gage, and this elicited change in cerebrospinal pressure. The patients we studied had no impairment of integrity of cranial bones and they were in a compensated condition.

Results and Discussion

It has been established that, in healthy subjects at rest, with the body in horizontal position, ultrasound attenuation (α) is in the range of 1.0 to 2.0 dB/cm in 69% of the cases, 2.0-3.0 dB/cm in 26.9% and over 3.0 dB/cm in 4.1%. It is known that α may have wider scatter when sounding the brain of different people, depending on the condition, properties and thickness of cranial bones [19]. However, there are changes in α during various functional tests, which are related to redistribution of fluids [20]. We studied the changes in α during 7-day antiorthostatic hypokinesia (ANOH) with a tilt angle of -8°, on 9 healthy men 25 to 40 years of age. We failed to demonstrate reliable changes in mean value of parameter α; however, we were impressed by the synchronous change in α for the right and left hemispheres, in the same direction, during the first hours of ANOH, probably due to redistribution of fluids in the skull.

Variuos types of waves were demonstrated during long-term recording of the echo signal in a quiet state. Figure 2 illustrates curves that show pulse and respiration waves, as well as third-order waves at a frequency of 1-2, 3-4 or 5-8/min, that are usually called Traube-Hering waves [10, 20, 21].

It was previously possible to record oscillatory processes in the brain only when examining patients using invasive methods. In addition to pulse and respiration waves, there has been description of slow waves at 1-2, 3-4 and 5-12/min [22] and so-called wave plateaus with a period of 5-20 min [23]. In our studies, we found respiration waves in 10% of the essentially healthy subjects, the amplitude of which exceed pulse waves in some cases (see Figure 2). In 20% of the cases, we demonstrated slow vasomotor waves at a frequency of 1-2 and 5-8/min in healthy subjects in horizontal position. The respiration waves and slow oscillations of blood and cerebrospinal fluid dynamics are not manifest in the cranial cavity of most healthy subjects, whereas pulse waves are present, and they can probably be of diagnostic value in dynamic observations. When conducting the tests in horizontal position, the parameter of pulsed attenuation of ultrasound (α_p) was in the range of 0.3 to 3.7 dB.

Reliable changes in α_p were demonstrated during the postural tests ($P<0.05$). Thus, in the orthostatic test (75°; Figure 3a), α_p dropped to 0.428±0.120 dB from 0.636±0.140 dB in horizontal position in the 10th min of the test; in the 1st min in horizontal position it returned to the base value and by the 5th min rose to 0.836±0.200 dB. In the subsequent antiorthostatic test (-30°) we observed reactions in different directions, which were characterized by increase in one group of subjects (11 people) and decrease in the other (19 people). Figure 3a illustrates this as a split curve α_p by the 5th min of the test.

The direction of change in α_p during the LBNP test was identical to the one found in the orthostatic test.

The changes in α_p during postural tests are definitely related to changes in dynamics of blood and cerebrospinal fluid in the skull. The different directions of changes in α_p during the antiorthostatic test merit special attention. The observed decline of α_p at -30° is apparently due to depression of pulsations of structural elements in the skull due to marked elevation of

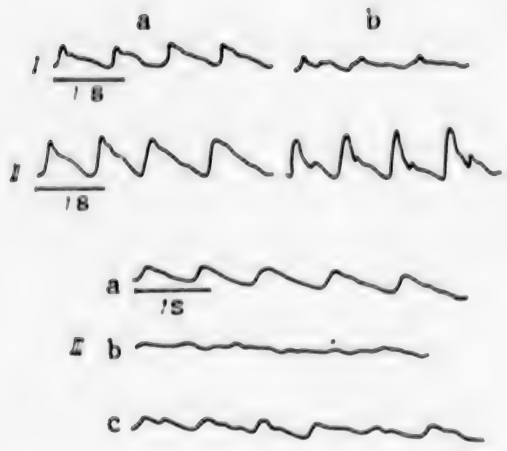

Figure 4.
Changes in reactivity of vascular system of the brain during various functional tests
I) before (a) and after (b) several drags on a cigarette
II) in waking state (a) and asleep (b)
III) before (a), during (b) and after (c) ligating carotid

intracranial pressure. This assumption is consistent with the experimental data obtained by Oka et al. [6], according to which there is first increase in amplitude of pulsation of the third ventricle of the brain with elevation of pressure and with further rise there is decrease in pulsation amplitude. N. K. Bogolepov et al. adhere to the same opinion [17].

Dynamic studies of α_p were conducted on 8 subjects submitted to 7-day ANOH (-8°; Figure 3b). As can be seen in this figure, after start of ANOH there is increase in α_p, which reaches a maximum by the end of the 1st day. On the 3d day of ANOH there is a tendency toward normalization of α_p and on the 7th day its value was close to the base level.

Changes in α_p and other characteristics of the pulsograms can also be observed (Figure 4) during other functional tests, such as dragging on a cigarette, testing before and during sleep, with ligation of the carotid, etc.

Studies were made of neurosurgical patients for quantitative evaluation of the observed changes in α_p; we arbitrarily effected a controllable change in their cerebrospinal pressure by means of drip infusion of saline endolumbarly, using the technique developed by Ye. Shevchikovskiy et al. [24]. We inserted a needle into the cerebrospinal canal, connected it to a pressure gage and recorded cerebrospinal pressure. We concurrently recorded the echo signal from the occipital bone and evaluated α_p of one of the cerebral hemispheres. From the obtained data we found the equation of linear regression ($P<0.01$) to determine cerebrospinal pressure (in mm water) according to pulsed attenuation of ultrasound (α_p, in dB): cereprospinal pressure = $b \cdot \alpha_p + a$, where b = 345.39 and a = 0.36.

One of the advantages of recording echo signals with fronto-occipital sounding is that it is possible to make a separate study of parameters of blood and cerebrospinal fluid dynamics of the hemispheres, which could be of deciding importance in the presence of different types of cerebral lesions. Moreover, when the sensor is placed on the forehead, it is unnecessary to profusely irrigate the site of contact of the sensor with the skin with oil. The absence of hair and good contact provide for a distinct and stable pattern, without interference or artifacts, which are observed when probing brain structures from the temporal region. In our opinion, frontal-occpital sounding does not create any discomfort and simplifies the technique of bioecholocation of the brain when conducting tests on healthy subjects involving long-term dynamic observation (during ANOH, LBNP and postural tests).

The proposed approach to studies of parameters of blood and cerebrospinal fluid dynamics is simple, since it does not require a detailed search and distinction of echo signals from intracerebral structures. With the technical capabilities of modern ultrasonic echolocators, there is no particular difficulty in obtaining a signal from the occpital bone.

The existence of a correlation between amplitude of pulsed attenuation of ultrasound in the brain and cerebrospinal pressure level makes it possible to use a noninvasive method for quantitative evaluation of intracranial pressure in both healthy and sick individuals.

In order to avoid any possible mistakes in interpretation of the obtained data when making practical use of the proposed method of bioecholocation in order to assess intracranial pressure and parameters of pulsed delivery of blood to the brain, it is apparently also necessary to take into consideration central hemodynamics, as the input to the intracranial cavity, as well as to find the position for a subject, in which it is possible to unequivocally determine the intracranial characteristics of blood and fluid dynamics.

This technique may find application in studies related to determination of intracranial volumetric correlations of fluids, before and after exposure to factors of simulated and real spaceflights.

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EXPERIMENTALLY PRODUCED BIPED MONKEYS AS A MODEL FOR MULTIPURPOSE RESEARCH IN GRAVITY BIOLOGY AND PHYSIOLOGY

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 6, Nov-Dec 83 (manuscript received 10 Jan 83) pp 81-85

[Article by G. S. Belkaniya and V. A. Dartsmeliya]

[Text] At the present time there is a rather large armamentarium of experimental resources for investigation of the effects of altered ambient gravity on animals. It includes diverse models that are used in ground-based experiments and in spaceflights. However, all this is used primarily to demonstrate the effects of weightlessness, i.e., relative or absolute decline of the effect of gravity on the body. Intensification of research in this direction is due to the practical demands of cosmonauts, the need to make it possible for man to spend a long time in space. For expressly this reason there are so diversified experimental and clinical models and studies of physiological effects of weightlessness. We refer, first of all, to the set of models of clinostatic and antiorthostatic hypokinesia, models submerged into immersion media, including the recently developed "dry immersion" method, models with vertical and inclined suspension of man and animals [1-3]. At the same time, in spite of the interest of researchers in the problem of accelerations and hypergravity, rotation on a centrifuge is still the only experimental means of making studies in this direction [4].

The impossibility of retaining under model conditions usual locomotor activity is a substantial limiting factor in the known ground-based models for the study of effects of gravity on the body. For this reason, such models are characterized by their marked static nature, which must be taken into consideration when interpreting the observed functional changes, assessing the latter as the consequence of exposure to two factors, hypokinesia and hypodynamia.

The model with inclined suspension of monkeys is more adequate to some extent in this respect [3]. As for the centrifuge model to test the effects of increased gravity, even in the case of slow rotation the occurring angular accelerations have an appreciable effect on the animal and modify significantly the effects of hypergravity.

The situation we have briefly analyzed is indicative of the existance of some disproportion between developments in the area of research on physiological effects of hypogravity and weightlessness, on the one hand, hypergravity and

natural gravity, on the other. One of the basic reasons for this is that there is a considerably more limited methodological base for studies of the effects of hypergravity, as well as absence of definie space experience, when the body could be exposed to a higher gravity than on earth.

No doubt, comparative physiological studies, consideration of philogenetic and ontogenetic direction of onset of structural and functional distinctions in animals and man with the change from a marine habitat to a terrestrial mode of life and then to semi-erect and erect stance, as well as spaceflights during which the body is in unsupported space, have largely determined our conceptions of the form-producing effect of gravity on animals and the biological significance of gravity. However, there are a number of problems of gravity biology, physiology of motion, as well as experimental anthropology, that require experimental elaboration.

We noticed the data in the literature obtained by means of experimentally induced bipedal stance, which are indicative of the marked form-producing influence of altered locomotion conditions on the rat skeleton [5, 6].

Observations of bipedal rats caused initial restraint in using this method for research in gravity biology. This was related primarily to the fact that, even in rats well-adapted to these conditions, there was no verticalization of the trunk. Animals whose forelegs were amputated moved on their hind legs, but their trunk rose very insignificantly above the horizontal plane [5]. In view of the distinct fixation of the trunk in the lumbar region and spine in a plane that is closer to horizontal, the angle between the long axes of the spine and thigh virtually failed to increase. Moreover, such a contrived position of the rat's spine is associated with a specific load on the ligaments and articulations, which leads to development of degenerative changes, which are particularly marked in the intervertebral disks. It is not by chance that experimental biped rats were used as a model of spondylarthrosis deformans [5].

The distinction of man's bipedal stance is that there is superposition of the long axes of the spine and thigh vertically. For this reason, it is expedient to use monkeys to simulate bipedia for a number of reasons. The main one is the evolutionary readiness of this species for change to semi-erect and erect position, which determined several of the corresponding morphological and functional transformations in simians. However, the evolutionary barrier in the way of orthograde stance and walking erect in anthropomorphic primates fixed the intermediate and incomplete nature of these transformations.

If the appropriate experimental conditions, under which this barrier could be overcome, were provided, it would be possible to investigate the direction of formation of functional adaptations in the body to earth's gravity, the vector of which coincides with the body's long axis. It is important to do this for both research on gravity physiology in the study of functional distinctions of the body with exposure to relatively greater influence of earth's gravity and for experimental anthropology in the study of transformations in the body related to the change to orthograde stance and walking erect.

In view of the foregoing, our objective here was to develop an experimental bipedal model in monkeys.

Figure 1. Film strip of free running by biped monkey 1 h after change to orthograde stance and erect walking. Sequence of frames from right to left.

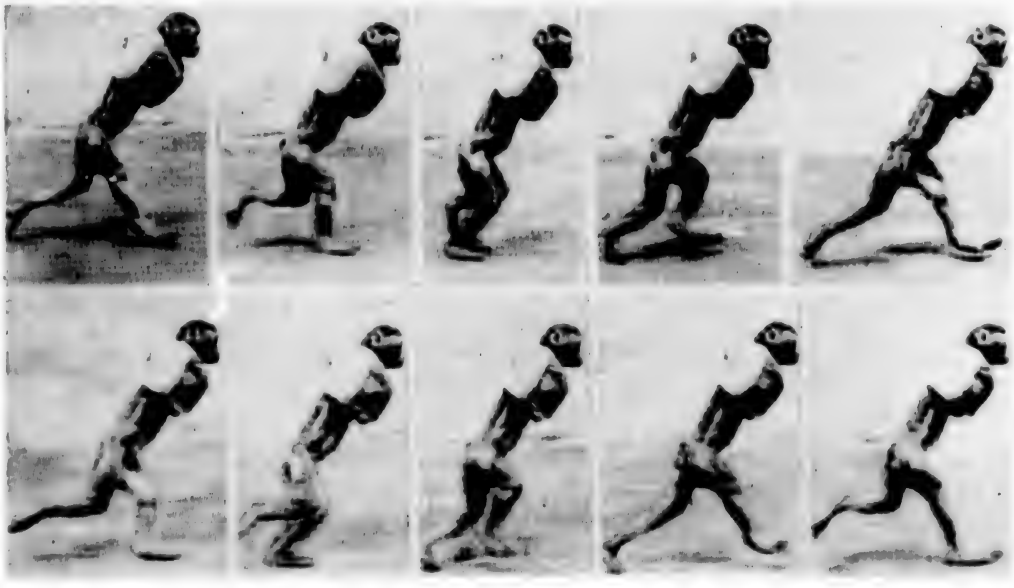

Figure 2. Film strip of monkey running freely after 1 month under experimental bipedal conditions. Sequence of frames from left to right and top to bottom.

Methods

The standard model of producing bipedal rats is to apply strap-like ligations to the forelegs of newborn rats, as a result of which self-amputation of the limbs occurs. With this model of modeling bipedia, some animals expire and the surviving ones are used in experiments. Amputation of adult rats raises the percentage of deaths. No doubt, use of this method on monkeys is an inadequate and rather traumatic procedure. This circumstance led us to use of the immobilization method. The different methods we used (tying the limbs in the back, taping the arms to the chest, sleeveless vest) were ineffective. With the inevitably tight taping or binding of the hands, compression of soft tissues soon leads to decubitus ulcers. In addition, the animals learn to use their bound extremities for support. Immobilization of the arms drawn to the back alters appreciably the natural position of joints and affects the animal's stance and locomotion, in addition to general complications. When an ordinary vest is put on, the animals free their arms quite rapidly and if the body strap is tightened a bedsore soon develops.

These difficulties of immobilizing the arms of monkeys were overcome by using a special one-piece garment. It was made of sturdy fabric in the form of a tube, the circumference of which corresponded to that of the animal's body with arms folded on the chest. The length of the free (external) part of the garment equaled the length from shoulder (base of the neck) to elbow. The length of the part that was folded under (inside) equaled the length from the elbow to the axilla. Both ends of the tube are gathered by means of circular ties. The top band is tied around the neck. For the bottom tie (folded part of the tube), openings were made on the posterior surface of the outer part of the tube along the midline at the level of the clavicles, through which the ends of the tapes were pulled to the outside. When they are tightened, the monkey's arms are in a pocket-type circular bag. The top tie prevents them from freeing the arms through the neck end of the tube, while the pocket formed by bending up the tube deprives the animal of the ability to free them through the bottom of the garment. The entire trunk does not have to be encircled with the tie. This eliminates the possibility of compression of soft tissues and development of decubitus ulcers.

There are several layers of material stitched to the front (chest) of the garment. This increases the strength of the garment, which is important because the monkey tries to tear the material with its teeth for the first few hours. A patch made of caprone (nylon-6) with a rubber lining [base] is sewn additionally on the chest part of the garment for hygienic purposes. This is done so that the front of the garment would not become soiled or wet when the animal eats and drinks. Tests revealed that, in such a special garment, monkeys are totally deprived of the ability to use their upper limbs for support and crawling, and they change to walking erect, which is the main objective of developing this model of experimental bipedia. The design of the garment makes it possible to keep the animals in bipedal conditions for many months without any injury to their pelage or integument.

Results and Discussion

The studies were conducted on 5 Macaca rhesus male monkeys 3-3.5 years of age. The animals were kept in a group in a cage for 180 days (the experiment is still in progress). Considering that this is the first report on experimental bipedal monkeys, in addition to methodological information it is expedient to furnish some data on general characteristics of physical condition, distinctions of stance and locomotion of biped animals.

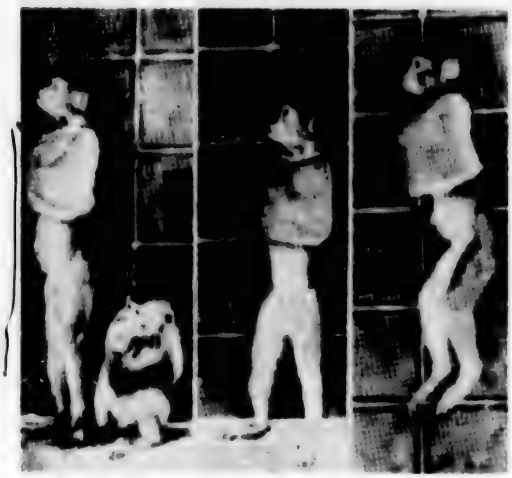

Figure 3.
Typical poses and distinctions of stance in biped monkeys when standing and jumping in place

For the first few hours after being deprived of the ability to use the upper extremities for support and climbing, the monkeys presented increased motor activity. There were noticeable difficulties in maintaining body equilibrium when the animals moved on their lower limbs. With abrupt straightening of the trunk and legs, the monkeys tumbled on their back or side. The unique conditions were reflected in a marked impairment of coordinating parts of the body when jumping. However, the animals adapted rather quickly to the experimental conditions, and after a few hours they had virtually solved the difficult biomechanical problem of maintaining equilibrium and coordination when moving about the cage on their lower limbs.

Figure 1 illustrates a film strip of a biped monkey running 1 h after immobilization of the upper extremities. The strip was filmed while the animal was running on a line next to a freely hanging cable. We can see well that, at first, the animal moves on half-bend extremities with marked inclination forward of the trunk. Such stance and locomotion features are typical in the first few hours for all experimental animals. However, after a few hours, there was more marked straightening of the trunk and lower limbs, and the characteristics of posture during walking and running came closer to those of beings that walk upright.

During the first month, the signs of orthograde stance increased in biped monkeys (Figure 2), with appearance of the signs of of body stance inherent in erect position. Figure 3 illustrates typical positions of biped monkeys when standing and jumping in place. The animal on the left clearly shows straightening of the trunk and lower limbs. The typical curvatures of the spine--thoracic kyphosis and lumbar lordosis--are well-seen along the posterior outline of the body. In 1 month, the animals assimilated all of the main locomotor forms of upright walking: running, jumping, climbing vertically with the legs supported in the corner walls of the cage.

The specific load on the pelvis and legs was associated with marked hypertrophy of muscles of the pelvis and lower extremities. The Table lists the relative changes in mass, volume of upper and lower extremities in the course of 3 months of walking upright in biped monkeys and control animals. We see distinct dissociation in the dynamics of changes in volumes of upper and lower limbs. It should be noted that, while in the course of the 1st month the forced restriction of movement of the upper limbs was associated with muscular atrophy, thereafter there was manifestation of relatively positive dynamics of changes in volume of the arm and forearm. In addition, we found significant increase in muscle mass of the thigh and lower leg. These findings are indicative of a specific orientation of plastic processes in the skeletal muscles of biped monkeys. A more marked functional load on the lower limbs also stimulates increase in muscle mass.

Relative changes (%) in mass and volume of animal limbs, as compared to background

Parameter	Background		1 month		3 months		
	exper.	control	exper.	contr	exper.	contr	P
Circumference							
arm	124±1	125±1	−6 (<0.005)	—	1 (>0.05)	8 (<0.001)	<0.05
forearm	117±1	120±1	−7 (<0.005)	—	−2 (>0.05)	3 (>0.05)	>0.05
thigh	117±3	181±3	18 (<0.001)	—	22 (<0.001)	8 (<0.001)	<0.001
lower leg	121±1	120±1	6 (<0.001)	—	12 (<0.001)	6 (<0.01)	<0.001
Weight of body	4100±76	4000±82	1 (>0.05)	—	16 (<0.001)	16 (<0.001)	>0.05

Note: Background values of circumference are given in millimeters and body weight in grams. The value of P when comparing to base data is given in parentheses.

These studies are indicative of rather marked evolutionary prerequisites in monkeys for assimilation of orthograde stance and upright walking. In spite of the ontogenetic fixation of structural distinctions of biomechanics of the skeleton and muscular system with the appropriate regulations, mature Macaca rhesus monkeys solve, virtually from the first presentation, the extremely

difficult mechanical problem of maintaining equilibrium when standing and walking upright. This circumstance is one more piece of vivic evidence of the morphofunctional similarity of the skeletomuscular system of this species and man, representatives of the same order of primates. We believe that research in this direction could yield new data for solving pressing problems of experimental primatology, physiology of posture and upright walking, interaction of analyzer systems of the body.

The change to permanent orthograde stance and upright walking in monkeys is actually adaptation to the effect of earth's gravity on the skeletomuscular system and hemodynamics of the animal. In this respect, the model we developed permits experimental investigations of the direction of structural and functional transformations in the body under the influence of earth's gravity.

The proposed model of experimental biped monkeys is an alternative for models of physiological effects of weightlessness (hypokinesia, immersion, vertical and inclined suspension). Bilateral comparison of data from studies of relatively altered influence of gravity on the body will help us gain a fuller idea about the biological significance of earth's gravity and the range of functional changes when animals adapt to altered ambient gravity.

In view of the fact that the results of animal experiments are extrapolated to man on certain assumptions, the use of biped monkeys that are well-adapted to earth's gravity in experiments with hypokinesia and on biological satellites could be a rather promising direction of research. There is reason to believe that additional information could be gained from such studies about the biological effects of hypogravity and weightlessness.

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REVIEW OF BOOK ON CONTROL OF POSTURE AND MOVEMENT

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[Review by V. A. Kislyakov of book "Reflex Control of Posture and Movement. Proceedings of an IBRO Symposium Held in Pisa on September 11-14 1978" in "Progress in Brain Research" edited by R. Granit and O. Pompeiano, Vol 50, 1979, Elsevier, North-Holland Biomedical Press, Amterdam, New York, Oxford, 827 pages]

[Text] The volume under review contains 78 articles distributed in 6 topical sections: 1) proprioceptive influences from receptors of the extremities; 2) proprioceptive influences from cervical receptors; 3) proprioceptive influences from receptors of ocular muscles; 4) labyrinthine influences on motor system; 5) ocular influences on motor system; 6) coordination of eye and head movements.

The book submits extensively the results of studies of proprioceptive influences on spinal motoneurons, supraspinal structures (cerebellum, somatosensory, motor cortex, etc.). It was reported that signals from the extremities travel to the motor cortex of the cat over two pathways): a) from the first group of muscle afferents and cutaneous afferents to cortical zone 3a and then via corticocortical pathways to the motor cortex; b) from group II and cutaneous afferents through the thalamic relays straight to the motor cortex. It is assumed that these pathways can participate in control of processes at the output of the motor cortex. Monosynaptic reflexes of the anterior extremities change more under the influence of otolith stimulation than the analogous reflexes of the posterior limbs. Optokinetic modulation was virtually the same for both anterior and posterior limb reflexes.

Studies of cats revealed that the spindles of muscular receptors of the neck are grouped into complexes of up to 10 units. The rate of conduction of cervical muscular afferents is 13 to 90 m/s, while their diameter is 16 μm. Golgi elements were found in muscle tendons. Pacini-like capsules were demonstrated near the spindles, as well as Golgi elements. No receptors were found in the connective tissue of intervertebral connections, although nerve fibers were demonstrated. There are marked descending projections to cervical segments of the spinal cord controlling the cervical muscles, which come from the cerebral cortex, brain stem and deep cerebellar nuclei. It was shown that there are tonic cervical excitatory and inhibitory influences on monosynaptic

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